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Techniques for Generating a "Real World" Ephemeris

Prepared by J. A. PEARSON, R. W. BRUCE, and R. C. GORE
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Engineering Science Operations
THE AEROSPACE CORPORATION

Prepared for SPACE AND MISSILE SYSTEMS ORGANIZATION
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FOREWORD

This report is published by The Aerospace Corporation, El Segundo, California, under Air Force Contract No. F04701-71-C-0172. This report, which documents research carried out from 1 January 1971 through 1 January 1972, was submitted for review and approval on 29 June 1971 to Herbert M. Briesacher, Maj, USAF.

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Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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ABSTRACT

This report documents the procedure for generating a "real world" ephemeris tape to be used by The Aerospace Corporation and selected contractors in Phase 0 of the Autonomous Navigation System (ANS) contract. A "real world" geopotential model was developed by modifying a state-of-the-art reference geopotential, using Kaula's degree variances as a guide. To obtain "real world" atmosphere data, the acceleration profile experienced by the first in a recent series of low altitude satellites to have an on-board low-g accelerometer was suitably scaled. The resulting ephemeris is displayed and subjected to various consistency tests.

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SECTION I

INTRODUCTION

A "real world" ephemeris tape has been generated for use by The Aerospace Corporation and selected contractors in Phase 0 of the Autonomous Navigation System (ANS) contract. This ephemeris is based on an analytic geopotential force model and an accelerometer data tape (in lieu of an atmosphere model).

To serve as a reference and a standard for comparison, a "model" ephemeris was also generated. This model ephemeris employed the same initial conditions that were to be used in the "real world" ephemeris and used force models that are representative of the state of the art.

Independent of the model ephemeris generation, a geopotential model which simulates the real world was developed. To represent the atmosphere, a span of accelerometer data was taken from an actual satellite flight whose orbit was quite similar to that chosen for the reference. These accelerations were scaled to meet certain criteria to make them suitable for use as a real world atmosphere representation. The detailed development of these models is described in the following sections.

Comparisons between the model and real world ephemerides were performed to ensure that the real world case satisfied certain consistency tests.

Figure 1-1 shows diagrammatically the tasks described above. The work on each task is documented in the section noted parenthetically within the box describing the task.

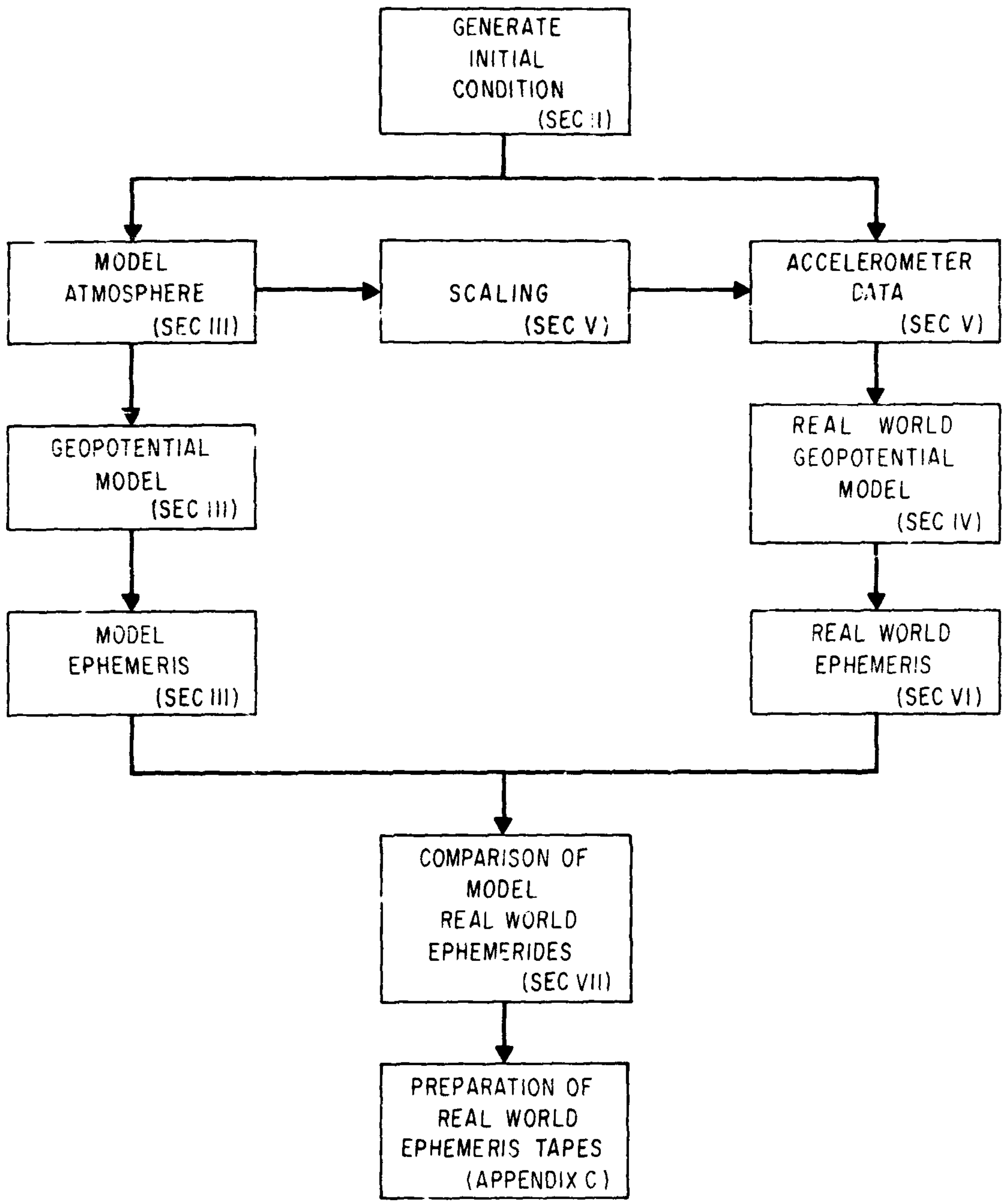

Figure I-1. Task Diagram of SNS Ephemeris Generation

SECTION II

INITIAL CONDITIONS

The low altitude reference orbit for the ANS has initial perigee occurring within one-half hour of local noon at approximately 45°N latitude. The initial apogee altitude was 200 n mi and perigee altitude was 80 n mi above a spherical earth; its period was about 89.7 min.

Epoch time for this orbit was chosen as 2230 GMT on 29 February 1980. The initial conditions are shown in Table II-1 in four coordinate representations. These are conditions at an ascending node for an orbit having the previously described characteristics.

The first set is an earth-centered inertial (ECI) set which has as its reference plane the true equator at epoch and as its reference direction the mean equinox at 0 hr GMT of the date of epoch.

The second set is an inertial spherical coordinate set having α and δ as the right ascension (measured from the X axis, positive eastward) and geocentric latitude (declination) of the vehicle; β is the angle between the velocity vector and the geocentric vertical (the vertical flight path angle); Az is the azimuth of the velocity vector from true north, measured eastward on a plane normal to the geocentric vertical; and R and V are the respective magnitudes of the position and velocity vectors.

The third set is an earth-fixed spherical coordinate set having λ and ϕ as the geodetic latitude and longitude of the vehicle; γ as the angle between the velocity vector and the geocentric horizontal (the horizontal flight path angle); and Az, R, and V as previously defined.

The fourth set is the classical element set, where a and e are the semi-major axis and eccentricty, respectively; i is the inclination of the orbit plane; Ω is the right ascension of the ascending node; ω is the argument of perigee, the angle between the direction of perigee, and the line of nodes measured from ascending node to perigee; and τ is a reference time indicating the time of last perigee passage in minutes from epoch.

Table II-1. Four Representations of Initial Conditions

(1) Cartesian (ECI)		(2) Spherical	
X	-1.59387494563E+7 ft	α	136.390753744 deg
Y	1.51851714534E+7 ft	δ	1.0E-20 deg
Z	3.84199431557E-15 ft	β	90.7298014230 deg
X	6.16441282935E+3 fps	Az	340 deg
Y	6.00674668844E+3 fps	R	2.20130059195E+7 ft
Z	2.36312409387E+4 fps	V	2.51498815029E+4 fps
(3) Earth-Fixed Spherical		**(4) Classical Elements**	
λ	0 deg	a	2.17763946916E+7 ft
ϕ	360 deg	e	1.67413647743E-2
γ	-0.7298014230 deg	i	110 deg
Az	340 deg	Ω	136.390753744 deg
R	2.20130059195E+7 ft	ω	131.193639651 deg
V	2.51498815029E+4 fps	τ	-57.36926627 min

The Greenwich hour angle at 0 hr GMT of the assumed epoch data is 157.9667413 deg. This value is needed to facilitate transformations among these four representations.

The reference ballistic coefficient ($C_D A/W$) for this vehicle is 0.02 ft^2/lb. This value is considered typical of future high drag satellite system configurations.

SECTION III

"MODEL" EPHEMERIS

The TRACE computer program (Ref. 1 and 2) was utilized in generating the model ephemeris. The initial conditions previously discussed were used to generate an ephemeris for 20 orbits spanning approximately 1-1/4 days.

Force models used in the model ephemeris included a 6th degree and order version of a Guier 8th degree and order geopotential (Ref. 3), and the Jacchia-Walker-Bruce atmosphere model (Ref. 4). A 90-day mean of the 10.7 cm solar flux F_{10}, denoted $\overline{F}_{10}$, is used as a reference about which the short-term decametric flux is measured. Values of $F_{10} = \overline{F}_{10} = 220$ w/M^2/cps were used in the model ephemeris. A value of the planetary magnetic index $a_P = 20$ was also used. Appendix A contains a series of plots showing the ground trace of this vehicle as a function of time. For reference and for later comparison purposes, Table III-1 gives the times and ECI coordinates of the vehicle at each ascending node.

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Table III-1. Nodal Conditions for "Model" Ephemeris

Rev No.	Time of Ascension Nodal Cross (Mo/Day/Yr Hr/Min/Sec)	Position (ECI) XYZ (ft)	Velocity (ECI) $\dot{X}\dot{Y}\dot{Z}$ (fps)
0	2/29/80 22/30/0.00	-1.59387495E+7 1.51831715E+7 3.84199432E-15	6.16441283E+3 6.00674669E+3 2.36312409E+4
1	2/29/80 23/59/34.88980	-1.59849728E+7 1.51290676E+7 -3.42450058E-4	6.14526310E+3 6.02746746E+3 2.36342563E+4
2	3/1/80 1/29/9.04968	-1.60306694E+7 1.50749261E+7 -1.27921077E-3	6.12582532E+3 6.04818772E+3 2.36374575E+4
3	3/1/80 2/58/42.38501	-1.60763279E+7 1.50203121E+7 -3.93344718E-4	6.10595310E+3 6.06958938E+3 2.36408159E+3
4	3/1/80 4/16/22.60609	-1.61222326E+7 1.49651661E+7 -3.21860488E-4	6.08579606E+3 6.09047463E+3 2.36442966E+4
5	3/1/80 5/57/46.87890	-1.61677347E+7 1.49098307E+7 -1.29691562E-3	6.06616627E+3 6.11094373E+3 2.36478441E+4
6	3/1/80 7/27/18.02516	-1.62126068E+7 1.48546061E+7 -5.61057958E-5	6.04703706E+3 6.13214743E+3 2.3652798E+4
7	3/1/80 8/56/48.31871	-1.62574412E+7 1.47994091E+7 -1.34453140E-3	6.02763290E+3 6.15356280E+3 2.36544996E+4
8	3/1/80 10/26/17.81324	-1.63022491E+7 1.47441290E+7 -4.84307362E-5	6.00814712E+3 6.17471305E+3 2.36575294E+4
9	3/1/80 11/55/46.47345	-1.63468743E+7 1.46889614E+7 -1.26815078E-3	5.98856274E+3 6.19570106E+3 2.36603321E+4

Table III-1. Nodal Conditions for "Model" Ephemeris (Continued)

Rev No.	Time of Ascension Nodal Cross (Mo/Day/Yr Hr/Min/Sec)	Position (ECI) XYZ (ft)	Velocity (ECI) $\dot{X}\dot{Y}\dot{Z}$ (fps)
10	3/1/80 13/25/14.30215	-1.63916332E+7 1.46338136E+7 -4.18009639E-4	5.96833727E+3 6.21608673E+3 2.36630337E+4
11	3/1/80 14/54/41.38993	-1.64363722E+7 1.45783174E+7 -2.46736766E-4	5.94752069E+3 6.23585677E+3 2.36659569E+4
12	3/1/80 16/24/7.75793	-1.64807430E+7 1.45224105E+7 -1.30417512E-3	5.92644969E+3 6.25589753E+3 2.36690683E+4
13	3/1/80 17/53/33.34407	-1.65248655E+7 1.44662676E+7 -6.31984487E-4	5.90592687E+3 6.27676825E+3 2.36720090E+4
14	3/1/80 12/22/58.06510	-1.65687876E+7 1.44100661E+7 -6.78497093E-5	5.88630149E+3 6.29783075E+3 2.36747293E+4
15	3/1/80 20/52/21.87667	-1.66124592E+7 1.43537098E+7 -3.22734601E-4	5.86662222E+3 6.31863642E+3 2.36775153E+4
16	3/1/80 22/21/44.78377	-1.66559668E+7 1.42970491E+7 -1.05750460E-3	5.84642459E+3 6.33935065E+3 2.36805229E+4
17	3/1/80 23/51/6.84696	-1.66991600E+7 1.42403605E+7 -1.30152780E-3	5.82597771E+3 6.35945009E+3 2.36837258E+4
18	3/2/80 1/20/28.09812	-1.67418053E+7 1.41837185E+7 -1.32891135E-3	5.80526738E+3 6.37930109E+3 2.36871191E+4
19	3/2/80 2/49/48.44448	-1.67842644E+7 1.41266781E+7 -1.32615034E-3	5.78411142E+3 6.39985957E+3 2.36906835E+4
20	3/2/80 4/19/7.90466	-1.68269602E+7 1.40690575E+7 -1.30997504E-3	5.76259368E+3 6.42012503E+3 2.36943783E+4

SECTION IV

"REAL WORLD" GEOPOTENTIAL

A. SIMULATED GRAVITY FIELD GENERATION

For the real world case, the geopotential was expressed as a spherical harmonic expansion of the following form:

$$U = \frac{GM}{r}\left\{1 + \sum_{n=2}^{N}\left(\frac{a_e}{r}\right)^n\left[\bar{C}_{no}\bar{P}_n(\sin\phi) + \sum_{m=1}^{n}\bar{P}_n^{-m}(\sin\phi)(\bar{C}_{nm}\cos m\lambda + \bar{S}_{nm}\sin m\lambda)\right]\right\} \quad \text{(IV-1)}$$

where

U = geopotential

GM = gravitational constant times the mass of the earth

a_e = equatorial radius of the earth

r = radial distance from the earth's center of mass

ϕ = geocentric latitude

λ = geocentric longitude

$\bar{P}_n^m$ = normalized associated Legendre functions

$\bar{C}_{nm}, \bar{S}_{nm}$ = normalized cosine and sine coefficients of the nth degree and mth order

When the gravity field is expressed as such a spherical harmonic expansion, it is completely described by the choice of spherical harmonic coefficients (C, S). This study thus required that a suitable set of C's and S's be selected.

The set of spherical harmonic coefficients used for this study was generated as follows. First, a set of C's and S's was selected from one of the currently available geopotentials published in the literature. Second,

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Table IV-1. Gravity Degree Variances

Degree	Mean of Coefficients with Standard Deviation About the Mean of Reference	Mean of Perturbations with Standard Deviation About Mean $\times 10^6$
2	-96.6 ± 216.6	0.0015 ± 0.036
3	0.798 ± 0.853	0.0072 ± 0.019
4	0.154 ± 0.525	0.0123 ± 0.120
5	-0.094 ± 0.361	-0.028 ± 0.075
6	-0.152 ± 0.216	-0.023 ± 0.054
7	0.026 ± 0.192	0.0018 ± 0.045
8	0.026 ± 0.131	-0.0069 ± 0.036
9	0.013 ± 0.118	0.0055 ± 0.042
10	-0.023 ± 0.095	-0.009 ± 0.035
11	-0.036 ± 0.076	0.014 ± 0.027
12	-0.0014 ± 0.109	0.0039 ± 0.033
13	0.015 ± 0.079	0.0083 ± 0.028
14	0.015 ± 0.081	-0.0036 ± 0.029
15	0.0081 ± 0.063	0.003 ± 0.032
16	-0.0151 ± 0.0685	-0.0095 ± 0.0278
17	-0.0032 ± 0.0539	-0.0003 ± 0.0268
18	-0.0043 ± 0.060	0.0006 ± 0.030
19	0.0036 ± 0.051	-0.0022 ± 0.029
20	-0.00066 ± 0.025	0.0037 ± 0.022
21	-0.0020 ± 0.011	0.00052 ± 0.029
22	-0.0011 ± 0.015	0.00012 ± 0.023
23	0.00055 ± 0.023	0.00284 ± 0.020
24	0.0027 ± 0.010	-0.0012 ± 0.021

perturbations were then algebraically added to the set of coefficients in a way that left the lower degree features of the field unchanged but introduced increasing amounts of variation with increasing degree. Third, additional coefficients were generated for those terms not provided in the original set to increase the degree of the resulting simulated gravity field to the maximum size permitted by existing software.

Perturbations to the reference field were generated in the following manner: First, a degree variance was chosen for every degree 2 through 24. Table IV-1 shows the degree variance used in generating this field, the values obtained and published by W. M. Kaula (Ref. 5), and the values obtained from the reference set. As can be seen from the table, the degree variances were chosen to introduce very small perturbations in the lower degree field with an increasing variation as upper degree fields were generated, until finally at 19th degree a field would be produced that roughly obeyed the properties reported by Kaula.

For every degree variance of Table IV-1 (column 1), a set of coefficient perturbations, $\overline{\Delta C}_{nm}$, $\overline{\Delta S}_{nm}$, was chosen from a random number generator such that the sum of the squares of these coefficients would satisfy the equation

$$\sigma_n^2 = \frac{1}{g_e^2(n - 1)^2} \sum_{m=0}^{n} \overline{\Delta C}^2_{nm} + \overline{\Delta S}^2_{nm} \qquad \text{(IV-2)}$$

where σ_n^2 is the degree variance and g_e is the mean equatorial gravity.

Finally, the coefficients generated by this process were algebraically added to the coefficients of identical degree and order in the reference set, and the result was then used as the final representation of the earth's gravity field.

Using the above method, a field was generated complete to 24th degree and order. This field above 19th degree is, essentially, a random field conforming only to the constraint of Eq. (IV-2). For 19th degree and under, the field is a slightly varied form of the reference field. This can be seen

Table IV-2. Geopotential Coefficient Statistics

Degree	Degree Variance Used in Generating Perturbation (mgal^2)	Degree Variance Reported by Kaula (Ref. 5)(mgal^2)	Degree Variance from Reference (mgal^2)
2	0.005	7.	7.6
3	0.01	44.	33.9
4	1.	30.	20.9
5	1.	10.	21.5
6	1.	24.	20.6
7	1.	3.	18.2
8	1.	23.	13.5
9	2.	22.	15.5
10	2.	15.	14.9
11	2.	18.	15.0
12	3.	7.	33.0
13	3.	15.	23.5
14	4.	23.	30.6
15	6.	22.	23.0
16	6.	6.	34.1
17	6.	12.	24.3
18	9.	19.	36.0
19	10.	10.	30.9
20	7.	7.	8.7
21	14.	14.	1.9
22	10.	10.	4.0
23	9.	9.	11.4
24	11.	11.	2.7

more clearly in Table IV-2, which gives the results of averaging both the reference set and the perturbation set of coefficients over all coefficients of the same degree. The sigma presented in Table IV-2 is the variance of the coefficients of a particular degree about the mean of the coefficients of that same degree. This sigma should not be interpreted as any measure of accuracy of the coefficients but is included to provide some measure of the variation of coefficients of a particular degree.

Table IV-3 presents the final set of coefficients generated for this study. These coefficients should be used with the expression for earth gravity potential given in Eq. (IV-1).

B. TEST OF SIMULATED GRAVITY FIELD

The field specified by Table IV-3 was tested for its effect upon the nominal orbit. This test was conducted by performing trajectory difference runs with TRACE (see Ref. 1). These difference runs were performed by taking the nominal epoch vector from Table II-1 as an initial condition from which an orbit was obtained by numerical integration of the gravity force model. The same process was then repeated with the perturbed gravity field. The difference between the two orbits at identical times was then resolved into in-track, radial, and cross-track differences.

First, a difference run was made between the Guier $n = 6$, $m = 6$ model ("model" geopotential) and the reference model. No atmosphere model was included. The purpose of this run was to establish a baseline for the behavior of a high-degree gravity field. (The Guier 6.6 geopotential uses a value of $GM = 1.4076538841E+16\ ft^3/sec^2$, while the reference model has a $GM = 1.4076468597E+16\ ft^3/sec^2$.) Figures IV-1a, b, and c show the behavior of the in-track, radial, and cross-track differences. The in-track difference shows a secular growth component of approximately 770 ft/rev together with a periodic component with a maximum excursion of 1500 ft; the radial difference shows a periodic variation with a maximum amplitude of approximately 700 ft; the cross-track difference has a maximum periodic difference of 1300 ft.

Table IV-3. "Real World" Normalized Geopotential Spherical Harmonic Coefficients

N	M	$\overline{C}_{nm}$	$\overline{S}_{nm}$
02	00	-0.48420E-3	0
02	01	-0.52757E-7	0.269052E-7
02	02	0.24560E-5	-0.13568E-5
03	00	0.973088E-6	0
03	01	0.201883E-5	0.241731E-6
03	02	0.914645E-6	-0.64224E-6
03	03	0.732356E-6	0.139657E-5
04	00	0.669659E-6	0
04	01	-0.61604E-6	-0.58214E-6
04	02	0.458155E-6	0.605959E-6
04	03	0.106926E-5	-0.88256E-7
04	04	-0.14290E-6	0.119265E-6
05	00	-0.57458E-7	0
05	01	0.986159E-8	0.125244E-9
05	02	0.728570E-6	-0.38968E-6
05	03	-0.41915E-6	-0.14221E-6
05	04	-0.38836E-6	-0.42354E-8
05	05	0.364591E-7	-0.71663E-6
06	00	-0.23179E-6	0
06	01	-0.62937E-7	-0.26636E-7
06	02	0.817727E-7	-0.39237E-6
06	03	0.359555E-7	-0.39050E-7
06	04	-0.77257E-7	-0.53799E-6
06	05	-0.28345E-6	-0.59325E-6
06	06	0.796188E-7	-0.23068E-6

N	M	$\overline{C}_{nm}$	$\overline{S}_{nm}$
07	00	0.160365E-6	0
07	01	0.192085E-6	0.605560E-7
07	02	0.259770E-6	0.143359E-6
07	03	0.322751E-6	-0.15450E-6
07	04	-0.32667E-6	-0.15535E-6
07	05	0.143604E-7	-0.46266E-8
07	06	-0.30176E-6	0.142523E-6
07	07	0.537338E-7	0.130910E-7
08	00	0.510865E-7	0
08	01	0.690357E-7	0.106908E-6
08	02	-0.57280E-7	-0.14529E-7
08	03	0.121137E-6	-0.98384E-7
08	04	-0.33922E-6	0.113135E-6
08	05	-0.78786E-7	0.111078E-6
08	06	-0.69232E-7	0.351645E-6
08	07	0.255853E-7	0.526569E-7
08	08	-0.11002E-6	0.948901E-7
09	00	-0.34882E-7	0
09	01	0.255080E-6	0.130273E-6
09	02	0.320793E-7	-0.15763E-6
09	03	-0.16022E-6	0.112325E-7
09	04	-0.69222E-7	0.442387E-7
09	05	0.402305E-7	-0.32521E-8
09	06	0.867828E-7	0.255222E-6
09	07	-0.10928E-6	-0.17379E-6
09	08	0.229342E-6	-0.17440E-7
09	09	-0.98775E-7	0.891216E-7

Table IV-3. "Real World" Normalized Geopotential Spherical Harmonic Coefficients (Continued)

N	M	$\overline{C}_{nm}$	$\overline{S}_{nm}$	N	M	$\overline{C}_{nm}$	$\overline{S}_{nm}$
10	00	0. 758787E-7	0	12	06	-0. 82840E-7	0. 804353E-7
10	01	-0. 34867E-7	-0. 18495E-6	12	07	0. 682487E-7	0. 789886E-7
10	02	0. 105952E-6	0. 706344E-7	12	08	-0. 19007E-7	0. 683604E-7
10	03	-0. 12594E-6	-0. 14879E-6	12	09	0. 767180E-7	0. 113637E-7
10	04	0. 287391E-8	-0. 89879E-7	12	10	0. 373138E-7	0. 544306E-7
10	05	-0. 57062E-7	-0. 46122E-7	12	11	0. 208459E-7	-0. 45799E-7
10	06	-0. 75825E-7	-0. 16755E-6	12	12	-0. 94194E-8	0. 113739E-7
10	07	0. 123326E-7	-0. 62076E-8				
10	08	-0. 44120E-7	-0. 72350E-7	13	00	-0. 28961E-7	0
10	09	0. 140846E-6	-0. 10200E-6	13	01	0. 439583E-7	0. 935374E-7
10	10	0. 123486E-6	-0. 48686E-7	13	02	0. 278303E-7	-0. 20455E-6
				13	03	0. 329141E-7	0. 180647E-6
11	00	-0. 67008E-8	0	13	04	-0. 58186E-7	-0. 13199E-7
11	01	-0. 77547E-7	-0. 16652E-6	13	05	0. 571087E-7	0. 196769E-6
11	02	0. 161544E-7	0. 284179E-7	13	06	0. 383022E-7	-0. 21669E-7
11	03	0. 254468E-7	-0. 19559E-6	13	07	-0. 65082E-8	-0. 35740E-7
11	04	-0. 46298E-7	-0. 11822E-6	13	08	0. 128901E-7	-0. 49418E-8
11	05	0. 889578E-8	-0. 25121E-8	13	09	0. 730744E-7	0. 724142E-7
11	06	-0. 54230E-7	0. 818400E-7	13	10	0. 333800E-7	0. 130152E-7
11	07	0. 664672E-7	-0. 25796E-7	13	11	-0. 35917E-8	0. 60160E-10
11	08	-0. 48235E-7	0. 482845E-7	13	12	-0. 24347E-7	0. 134564E-6
11	09	-0. 34852E-8	0. 823436E-7	13	13	-0. 21248E-7	0. 300477E-7
11	10	-0. 60133E-7	-0. 54760E-7				
11	11	0. 426106E-7	-0. 47852E-7	14	00	-0. 15236E-6	0
				14	01	-0. 56378E-7	-0. 10758E-6
12	00	0. 106234E-6	0	14	02	0. 166440E-6	0. 119949E-6
12	01	0. 277775E-8	0. 766575E-8	14	03	-0. 15003E-6	-0. 28323[illegible]E-7
12	02	-0. 25737E-6	-0. 12560E-6	14	04	0. 278466E-6	0. 563923E-7
12	03	0. 267978E-6	0. 119924E-6	14	05	-0. 42717E-7	-0. 68000E-8
12	04	-0. 31626E-6	-0. 32702E-7	14	06	0. 698756E-7	0. 5[illegible]2935E-7
12	05	-0. 81811E-9	-0. 61136E-7	14	07	-0. 25607E-7	0. 181216E-7

Table IV-3. "Real World" Normalized Geopotential Spherical Harmonic Coefficients (Continued)

N	M	$\overline{C}_{nm}$	$\overline{S}_{nm}$
14	08	0.450234E-7	0.103226E-7
14	09	0.576751E-7	-0.18309E-8
14	10	0.902127E-7	0.676386E-7
14	11	-0.38411E-7	-0.31449E-7
14	12	0.580309E-9	-0.59799E-7
14	13	0.119424E-7	0.154636E-7
14	14	-0.64765E-7	0.364691E-7
15	00	0.119870E-6	0
15	01	-0.44962E-7	0.182475E-7
15	02	-0.13405E-7	0.109952E-6
15	03	0.139999E-6	-0.70536E-7
15	04	0.139909E-6	0.541279E-7
15	05	-0.37062E-7	-0.10506E-6
15	06	-0.33136E-7	0.390408E-7
15	07	0.470276E-7	0.386850E-7
15	08	-0.11108E-8	0.395489E-7
15	09	-0.21101E-8	0.779548E-7
15	10	0.504202E-7	0.518126E-7
15	11	-0.87591E-7	0.942663E-8
15	12	-0.12639E-7	0.203138E-7
15	13	-0.68930E-7	-0.52061E-7
15	14	0.116997E-7	-0.29388E-7
15	15	-0.45651E-8	-0.61453E-7
16	00	0.610667E-7	0
16	01	0.826119E-7	0.702307E-7
16	02	-0.18393E-6	-0.44119E-8
16	03	0.935763E-7	-0.22311E-8
16	04	-0.23344E-6	-0.18945E-7
16	05	0.631531E-7	-0.90713E-9
16	06	-0.80586E-7	-0.45799E-7
16	07	-0.22932E-7	-0.60154E-7

N	M	$\overline{C}_{nm}$	$\overline{S}_{nm}$
16	08	-0.86519E-7	-0.61993E-7
16	09	-0.68630E-8	-0.91682E-7
16	10	-0.94601E-7	-0.31916E-7
16	11	0.149005E-7	-0.48102E-7
16	12	-0.71449E-8	-0.26615E-7
16	13	-0.23961E-7	0.382743E-7
16	14	0.245551E-7	-0.51547E-7
16	15	0.485409E-7	-0.87422E-7
16	16	-0.49682E-7	0.142786E-7
17	00	-0.40303E-7	0
17	01	-0.13606E-7	-0.58990E-7
17	02	0.107391E-8	-0.70914E-7
17	03	-0.72390E-8	0.101955E-6
17	04	-0.46689E-7	0.342571E-9
17	05	0.449471E-7	0.129511E-6
17	06	-0.50134E-7	-0.10703E-6
17	07	-0.44882E-7	-0.10686E-6
17	03	-0.19967E-7	0.903700E-7
17	09	0.440611E-7	0.246408E-7
17	10	-0.68775E-7	0.235640E-8
17	11	-0.25106E-7	-0.19014E-7
17	12	0.249397E-7	0.759679E-7
17	13	0.161100E-7	0.496739E-7
17	14	-0.7956E-10	-0.25362E-7
17	15	0.103419E-7	0.827257E-7
17	16	-0.43663E-7	-0.34518E-7
17	17	-0.98659E-8	-0.26360E-7
18	00	-0.79240E-7	0
18	01	-0.41074E-7	0.680828E-7
18	02	0.848806E-7	0.107642E-6
18	03	-0.71583E-7	-0.10741E-6
18	04	0.176555E-6	0.273848E-7

Table IV-3. "Real World" Normalized Geopotential Spherical Harmonic Coefficients (Continued)

N	M	$\overline{C}_{nm}$	$\overline{S}_{nm}$	N	M	$\overline{C}_{nm}$	$\overline{S}_{nm}$
18	05	-0.32811E-8	0.799469E-7	19	17	0.373620E-7	-0.58626E-7
18	06	0.953033E-7	-0.34436E-7	19	18	0.890505E-7	-0.59496E-7
18	07	-0.54536E-7	-0.71969E-7	19	19	-0.17153E-7	0.542653E-7
18	08	0.197630E-7	0.194518E-7				
18	09	-0.65944E-7	0.213571E-7	20	00	0.108785E-6	0
18	10	-0.87832E-9	0.605422E-7	20	01	-0.33580E-7	0.229822E-7
18	11	0.498471E-8	-0.56496E-7	20	02	0.306763E-7	-0.40429E-8
18	12	0.264072E-8	-0.49071E-7	20	03	-0.13322E-8	0.214574E-7
18	13	0.230824E-7	-0.65927E-7	20	04	-0.25799E-7	0.296186E-7
18	14	0.198402E-7	-0.67111E-7	20	05	-0.79996E-8	0.334365E-7
18	15	-0.33174E-7	-0.47239E-7	20	06	0.306858E-7	0.239531E-7
18	16	0.298156E-7	0.125934E-7	20	07	0.118478E-7	0.209380E-7
18	17	-0.53221E-7	-0.40016E-7	20	08	-0.16532E-7	-0.10169E-7
18	18	-0.18576E-7	-0.28969E-7	20	09	-0.29160E-7	-0.11673E-7
				20	10	0.250519E-8	0.249325E-7
19	00	0.360353E-7	0	20	11	0.265501E-8	0.241596E-7
19	01	0.831927E-8	0.146958E-6	20	12	0.152711E-7	0.391129E-7
19	02	0.134270E-7	0.205615E-7	20	13	-0.23834E-8	-0.80699E-8
19	03	0.723332E-8	-0.76579E-7	20	14	0.435379E-7	0.182584E-7
19	04	0.547610E-7	-0.44901E-8	20	15	-0.63460E-7	-0.43584E-7
19	05	-0.31882E-7	-0.12626E-6	20	16	-0.12641E-6	-0.69055E-8
19	06	-0.77506E-7	0.474491E-7	20	17	-0.16979E-7	-0.22005E-7
19	07	0.668100E-7	0.335062E-7	20	18	0.303597E-7	0.328549E-7
19	08	0.959483E-7	-0.10055E-6	20	19	-0.10027E-7	-0.20999E-7
19	09	0.232994E-7	-0.15549E-7	20	20	0.148501E-7	0.255208E-8
19	10	0.143453E-7	-0.30221E-7				
19	11	0.550503E-7	0.574992E-7	21	00	-0.63622E-7	0
19	12	0.128344E-8	0.415871E-8	21	01	-0.22181E-7	0.306106E-7
19	13	0.228003E-7	0.31810E-10	21	02	0.252255E-7	0.408729E-7
19	14	-0.30661E-7	0.139066E-7	21	03	0.424342E-7	-0.14107E-7
19	15	-0.18375E-7	-0.76155E-7	21	04	0.101995E-7	-0.34651E-7
19	16	-0.11124E-6	-0.14544E-7	21	05	0.406187E-7	-0.45851E-7

Table IV-3. "Real World" Normalized Geopotential Spherical Harmonic Coefficients (Continued)

N	M	$\bar{C}_{nm}$	$\bar{S}_{nm}$
21	06	-0.47136E-7	-0.23154E-7
21	07	0.215981E-7	-0.25265E-7
21	08	-0.22307E-8	-0.38647E-7
21	09	0.227568E-7	-0.12631E-7
21	10	0.397897E-7	-0.10542E-8
21	11	0.696079E-8	-0.21976E-7
21	12	0.926007E-8	-0.28885E-7
21	13	0.383861E-7	-0.13695E-7
21	14	-0.29024E-7	0.115217E-7
21	15	0.308850E-7	0.197129E-7
21	16	0.204000E-7	-0.42410E-7
21	17	0.608111E-8	-0.44800E-7
21	18	-0.39750E-7	-0.14446E-7
21	19	0.303184E-7	0.414327E-7
21	20	-0.17193E-7	0.356467E-7
21	21	0.136428E-7	-0.20328E-7
22	00	-0.26905E-7	0
22	01	0.201011E-7	-0.23997E-7
22	02	-0.19709E-8	0.128098E-7
22	03	-0.21604E-7	-0.13473E-7
22	04	-0.30189E-7	0.250485E-7
22	05	-0.32913E-7	-0.17341E-7
22	06	0.337159E-7	-0.32529E-7
22	07	0.384996E-7	-0.26561E-7
22	08	0.494668E-8	0.316952E-7
22	09	-0.16983E-7	-0.20429E-8
22	10	0.171803E-7	-0.53333E-8
22	11	0.169672E-7	-0.20457E-7
22	12	-0.24645E-7	-0.23631E-7
22	13	-0.33008E-8	0.398652E-7
22	14	-0.49190E-8	0.658080E-8

N	M	$\bar{C}_{nm}$	$\bar{S}_{nm}$
22	15	0.493904E-7	0.107119E-7
22	16	0.167609E-7	-0.51393E-7
22	17	-0.26816E-8	0.300204E-7
22	18	0.382741E-7	-0.18752E-7
22	19	-0.17776E-7	-0.29825E-7
22	20	0.341486E-7	-0.67049E-8
22	21	0.367985E-7	-0.21711E-7
22	22	-0.86883E-8	-0.19705E-7
23	00	-0.42110E-8	0
23	01	0.133217E-8	0.173212E-9
23	02	0.179314E-7	0.338670E-7
23	03	0.309501E-7	0.203054E-7
23	04	0.256717E-7	-0.10493E-7
23	05	0.117139E-7	-0.29354E-7
23	06	0.398542E-8	0.312782E-7
23	07	-0.27806E-7	0.201798E-7
23	08	0.592375E-8	-0.13298E-7
23	09	-0.99354E-8	0.188708E-7
23	10	0.305142E-7	-0.19015E-7
23	11	-0.19849E-7	-0.24617E-7
23	12	0.463131E-7	-0.60050E-7
23	13	0.382767E-9	-0.54632E-8
23	14	0.193972E-7	-0.15876E-7
23	15	-0.21170E-7	0.236010E-7
23	16	0.129718E-6	-0.12236E-7
23	17	0.200601E-7	0.288960E-7
23	18	-0.27388E-7	-0.13375E-7
23	19	0.259457E-8	0.120734E-7
23	20	-0.27982E-7	-0.28385E-7
23	21	0.148752E-7	0.822857E-8
23	22	-0.34170E-7	-0.19524E-7
		-0.51707E-8	0.196150E-7

Table IV-3. "Real World" Normalized Geopotential Spherical Harmonic Coefficients (Continued)

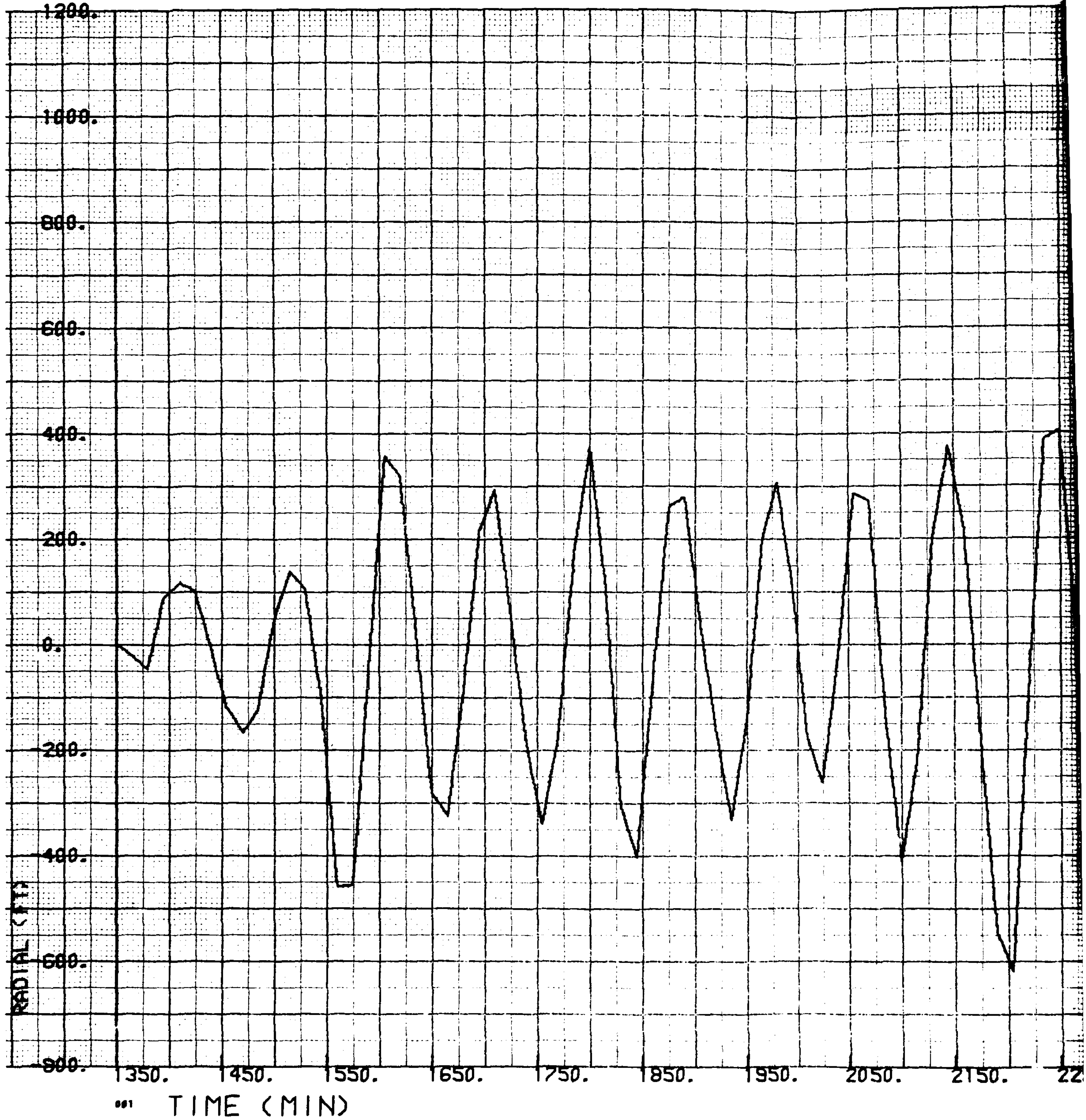
N	M	$\overline{C}_{nm}$	$\overline{S}_{nm}$	N	M	$\overline{C}_{nm}$	$\overline{S}_{nm}$
18	05	-0.32811E-8	0.799469E-7	19	17	0.373620E-7	-0.58626E-7
18	06	0.953033E-7	-0.34436E-7	19	18	0.890505E-7	-0.59496E-7
18	07	-0.54536E-7	-0.71969E-7	19	19	-0.17153E-7	0.542653E-7
18	08	0.197630E-7	0.194518E-7				
18	09	-0.65944E-7	0.213571E-7	20	00	0.108785E-6	0
18	10	-0.87832E-9	0.605422E-7	20	01	-0.33580E-7	0.229822E-7
18	11	0.498471E-8	-0.56496E-7	20	02	0.306763E-7	-0.40429E-8
18	12	0.264072E-8	-0.49071E-7	20	03	-0.13322E-8	0.214574E-7
18	13	0.230824E-7	-0.65927E-7	20	04	-0.25799E-7	0.296186E-7
18	14	0.198402E-7	-0.67111E-7	20	05	-0.79996E-8	0.334365E-7
18	15	-0.33174E-7	-0.47239E-7	20	06	0.306858E-7	0.239531E-7
18	16	0.298156E-7	0.125934E-7	20	07	0.118478E-7	0.209380E-7
18	17	-0.53221E-7	-0.40016E-7	20	08	-0.16532E-7	-0.10169E-7
18	18	-0.18576E-7	-0.28969E-7	20	09	-0.29160E-7	-0.11673E-7
				20	10	0.250519E-8	0.249325E-7
19	00	0.360353E-7	0	20	11	0.265501E-8	0.241596E-7
19	01	0.831927E-8	0.146958E-6	20	12	0.152711E-7	0.391129E-7
19	02	0.134270E-7	0.205615E-7	20	13	-0.23834E-8	-0.80699E-8
19	03	0.723332E-8	-0.76579E-7	20	14	0.435379E-7	0.182584E-7
19	04	0.547610E-7	-0.44901E-8	20	15	-0.63460E-7	-0.43584E-7
19	05	-0.31882E-7	-0.12626E-6	20	16	-0.12641E-6	-0.69055E-8
19	06	-0.77506E-7	0.474491E-7	20	17	-0.16979E-7	-0.22005E-7
19	07	0.668100E-7	0.335062E-7	20	18	0.303597E-7	0.328549E-7
19	08	0.959483E-7	-0.10055E-6	20	19	-0.10027E-7	-0.20999E-7
19	09	0.232994E-7	-0.15549E-7	20	20	0.148501E-7	0.255208E-8
19	10	0.143453E-7	-0.30221E-7				
19	11	0.550503E-7	0.574992E-7	21	00	-0.63622E-7	0
19	12	0.128344E-8	0.415871E-8	21	01	-0.22181E-7	0.306106E-7
19	13	0.228003E-7	0.31810E-10	21	02	0.252255E-7	0.408729E-7
19	14	-0.30661E-7	0.139066E-7	21	03	0.424342E-7	-0.14107E-7
19	15	-0.18375E-7	-0.76155E-7	21	04	0.101995E-7	-0.34651E-7
19	16	-0.11124E-6	-0.14544E-7	21	05	0.406187E-7	-0.45851E-7

Table IV-3. "Real World" Normalized Geopotential Spherical Harmonic Coefficients (Continued)

N	M	$\bar{C}_{nm}$	$\bar{S}_{nm}$	N	M	$\bar{C}_{nm}$	$\bar{S}_{nm}$
24	00	0.422303E-7	0	24	13	0.249900E-7	-0.20730E-8
24	01	-0.15215E-8	-0.34873E-7	24	14	-0.53486E-7	-0.12466E-8
24	02	0.108446E-7	0.151859E-7	24	15	0.535485E-7	-0.82934E-8
24	03	0.211630E-7	0.207832E-8	24	16	0.478664E-7	-0.10137E-7
24	04	-0.31688E-7	-0.61802E-8	24	17	-0.11024E-7	0.177626E-7
24	05	0.101969E-7	-0.11732E-7	24	18	0.182117E-7	-0.58285E-8
24	06	0.203522E-7	0.121721E-8	24	19	0.107197E-7	-0.33855E-7
24	07	0.339597E-7	-0.32352E-7	24	20	0.291973E-7	-0.22154E-7
24	08	0.251321E-7	-0.32292E-7	24	21	-0.17687E-7	-0.16306E-7
24	09	-0.88687E-8	0.281510E-7	24	22	0.158528E-7	0.107295E-7
24	10	-0.27586E-7	0.406940E-8	24	23	0.303773E-7	-0.15012E-8
24	11	0.100996E-7	-0.18150E-7	24	24	0.270652E-7	-0.33997E-7
24	12	-0.43977E-8	-0.12029E-7				

Next a difference run was made between the reference model and the model defined by Table IV-3, the simulated gravity field. These in-track, radial, and cross-track differences are presented in Figures IV-2a, b, and c. The in-track difference shows a secular growth of approximately 280 ft/rev plus two periodic components: one with a period of 1 rev and an amplitude of approximately 800 ft and the other with a period of about 12 revs and an amplitude of 1300 ft. The radial difference plot shows a 1 rev periodic component with maximum amplitude of approximately 700 ft, as does the cross-track difference plot. As before, these data do not include an atmosphere force model.

It was concluded from these results that the simulated gravity field produces orbit perturbations which differ significantly from those of the nominal gravity field but which are not unrealistically large. The results of these difference runs should not be interpreted as estimates of ephemeris uncertainties, since by suitable orbit determination techniques these differences would be drastically reduced in actual practice. The plots illustrate one of the possible shortcomings of this simulated model, i.e., the field is too smooth. Although this field is as extensive as the present state of the art, there is reason to believe that a 24th degree and order model is still significantly smoother than that experienced by a vehicle moving in the earth's gravity field.


1200.
1000.
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-600.
-800.
RADIAL (FT)
1350.
1450.
1550.
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1750.
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1950.
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TIME (MIN)

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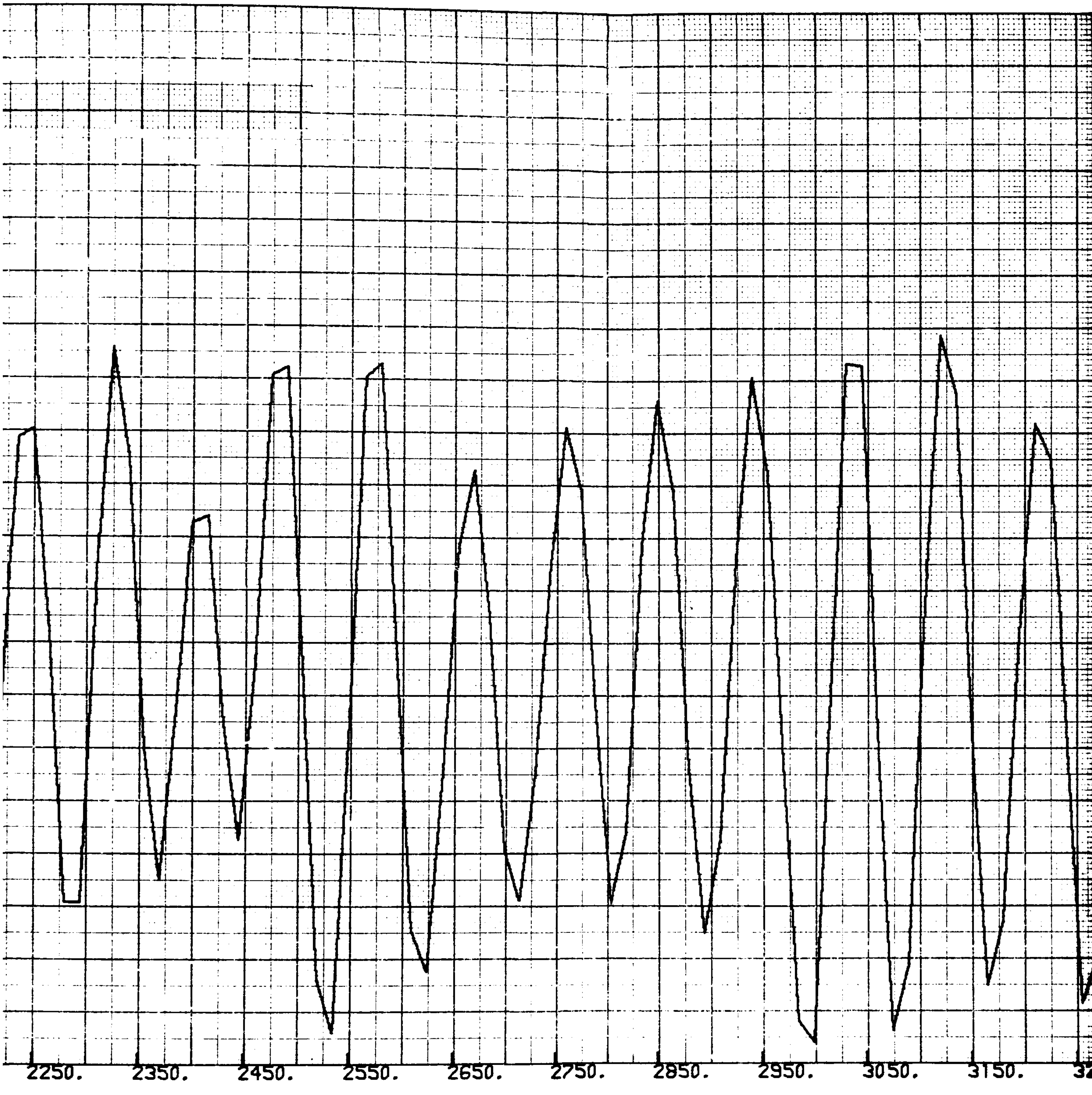


Figure IV-ia. Intrack Difference Between "Model" (
and Reference Geopotential (19, 19) A

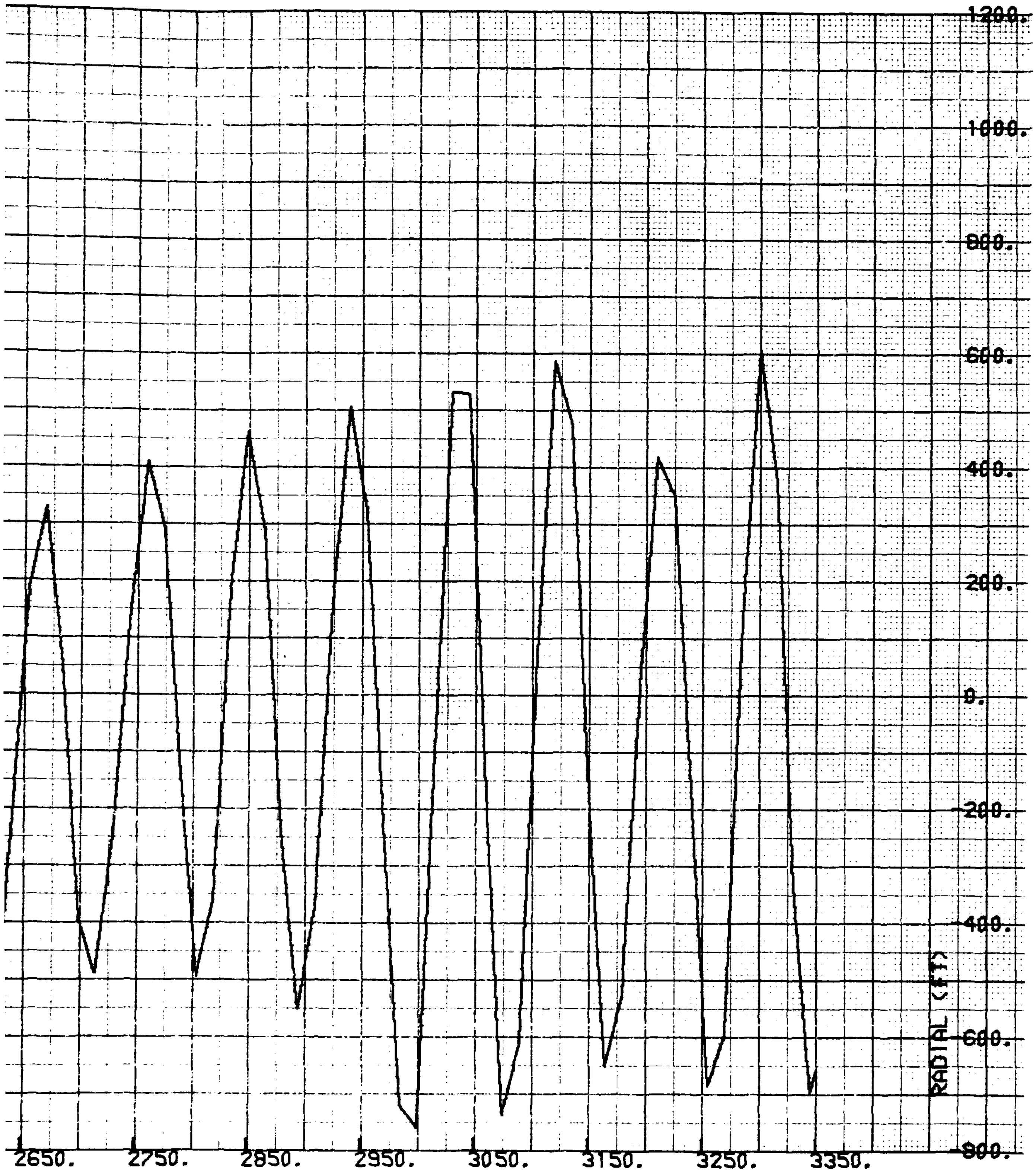
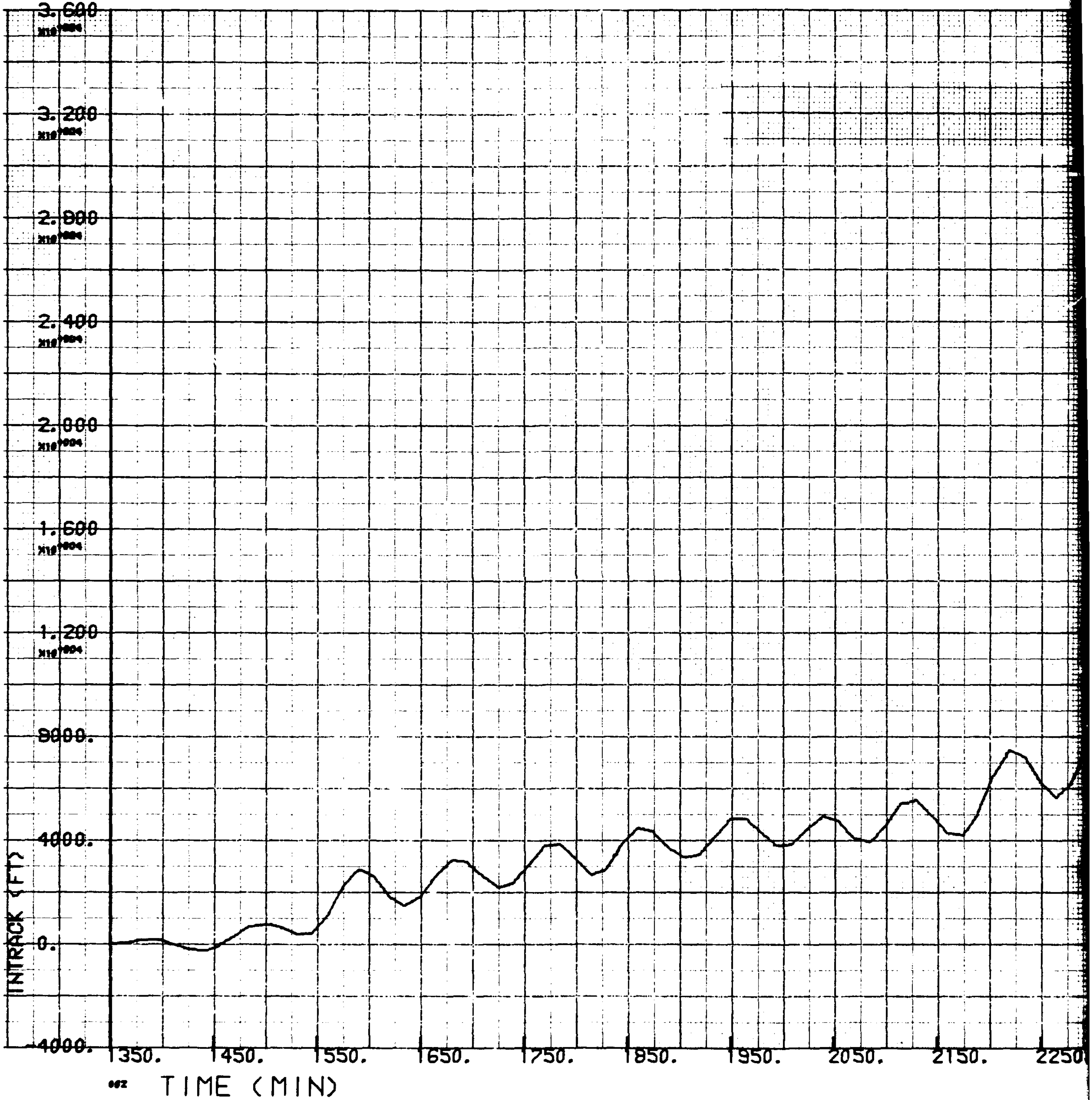


Figure IV-ia. Intrack Difference Between "Model" (6, 6) Geopotential and Reference Geopotential (19, 19) Atmosphere



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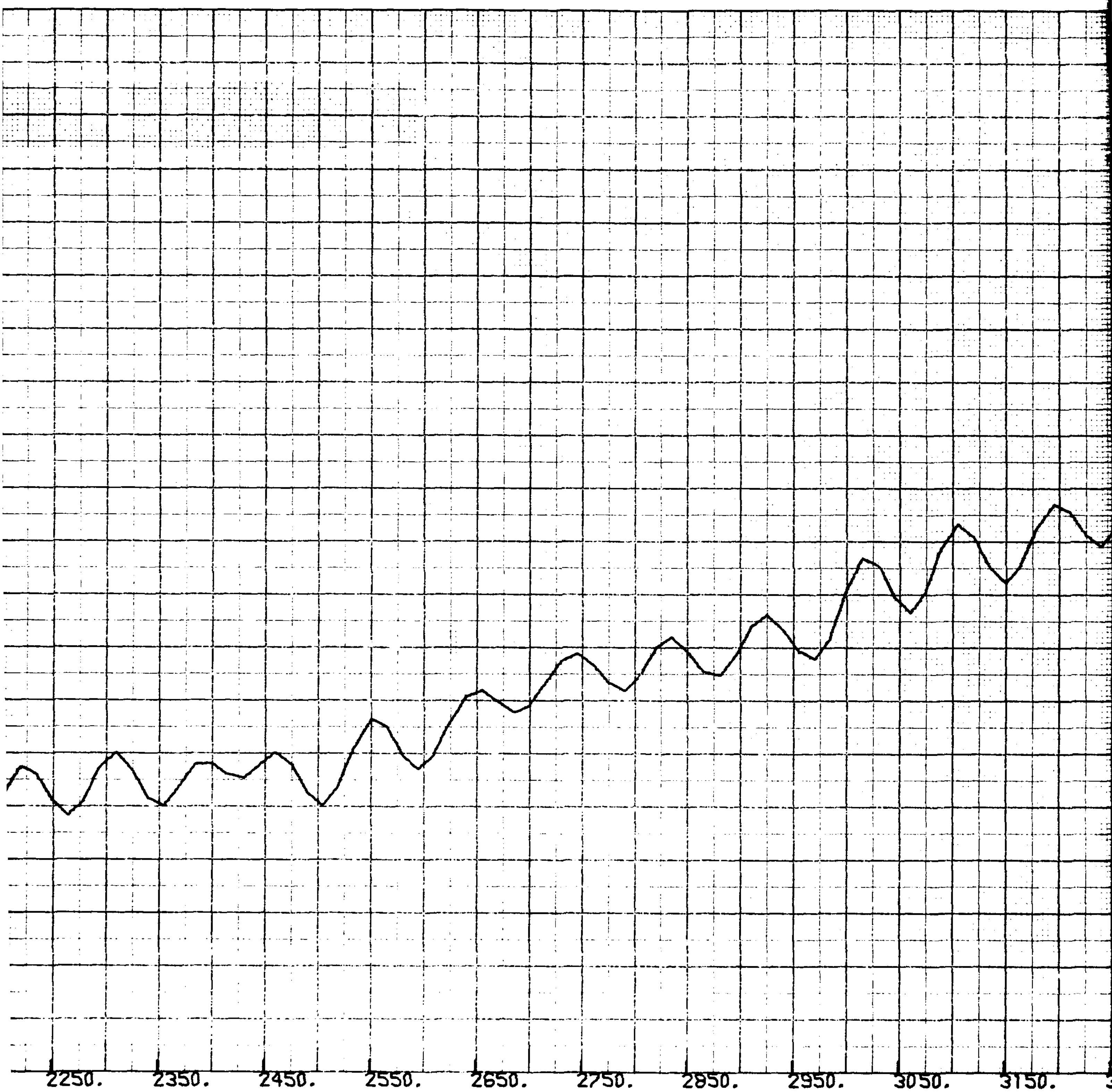

Figure IV-ib. Radial Difference Between "Model"

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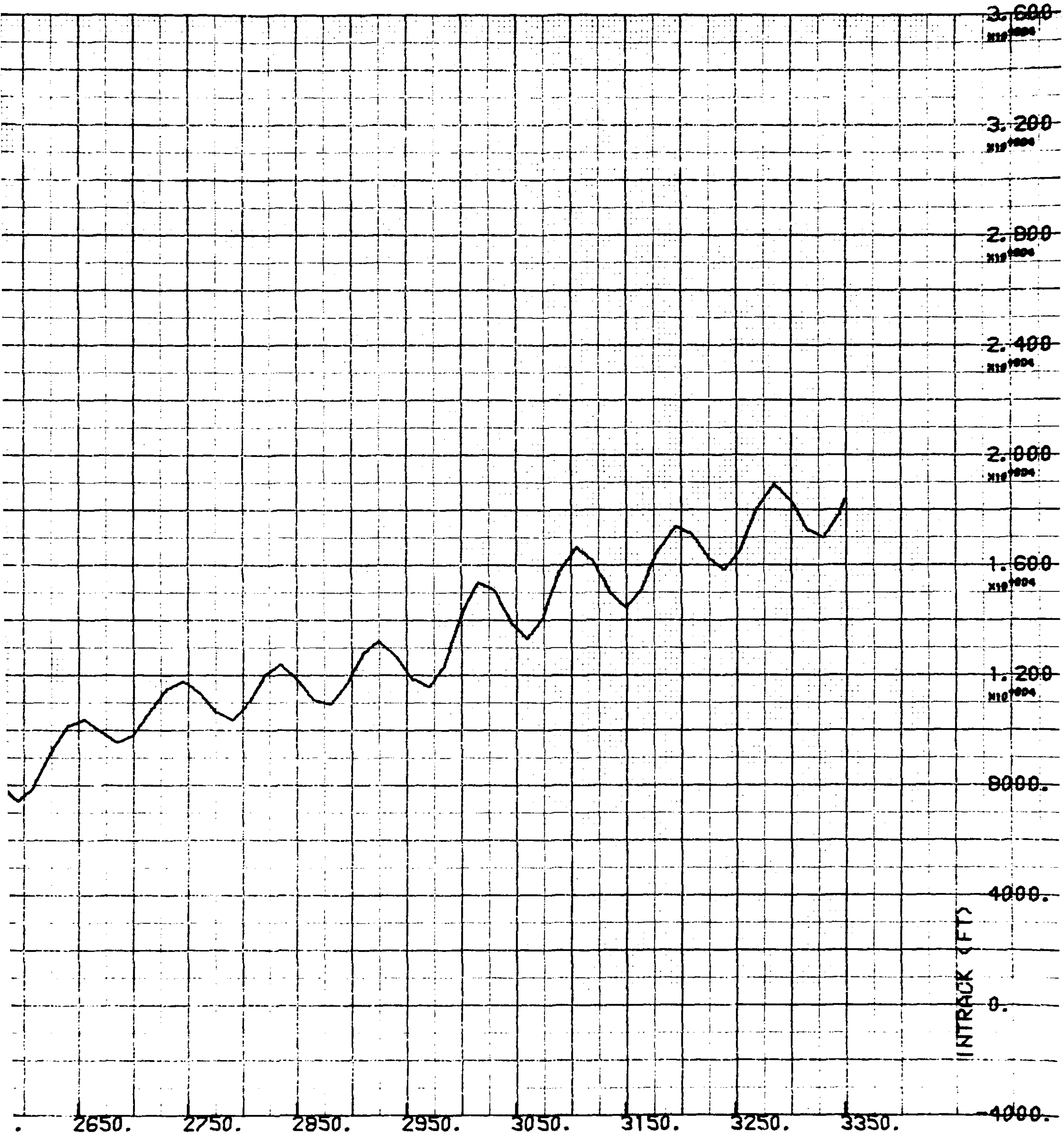
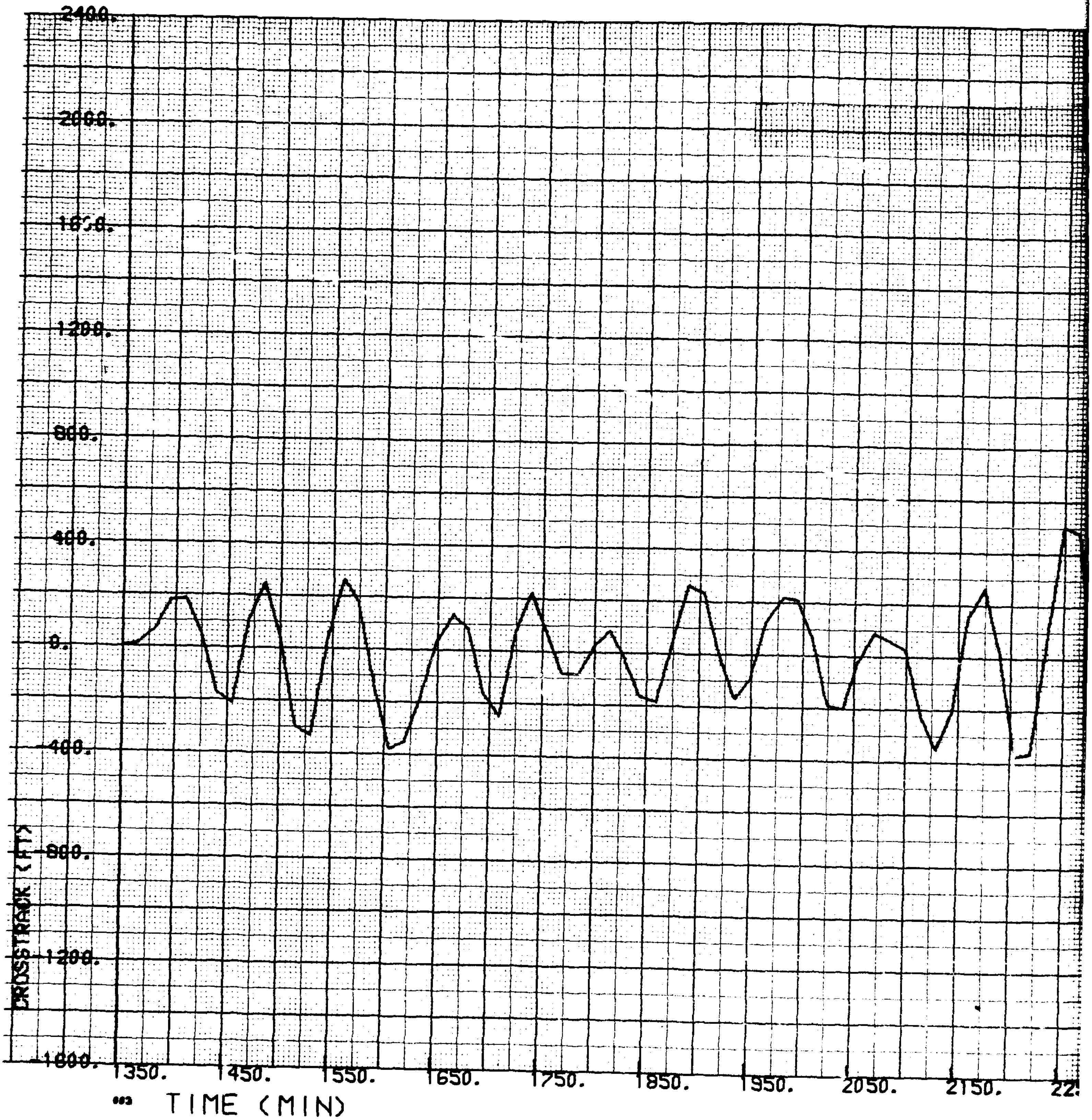


Figure IV-ib. Radial Difference Between "Model" and Reference

C



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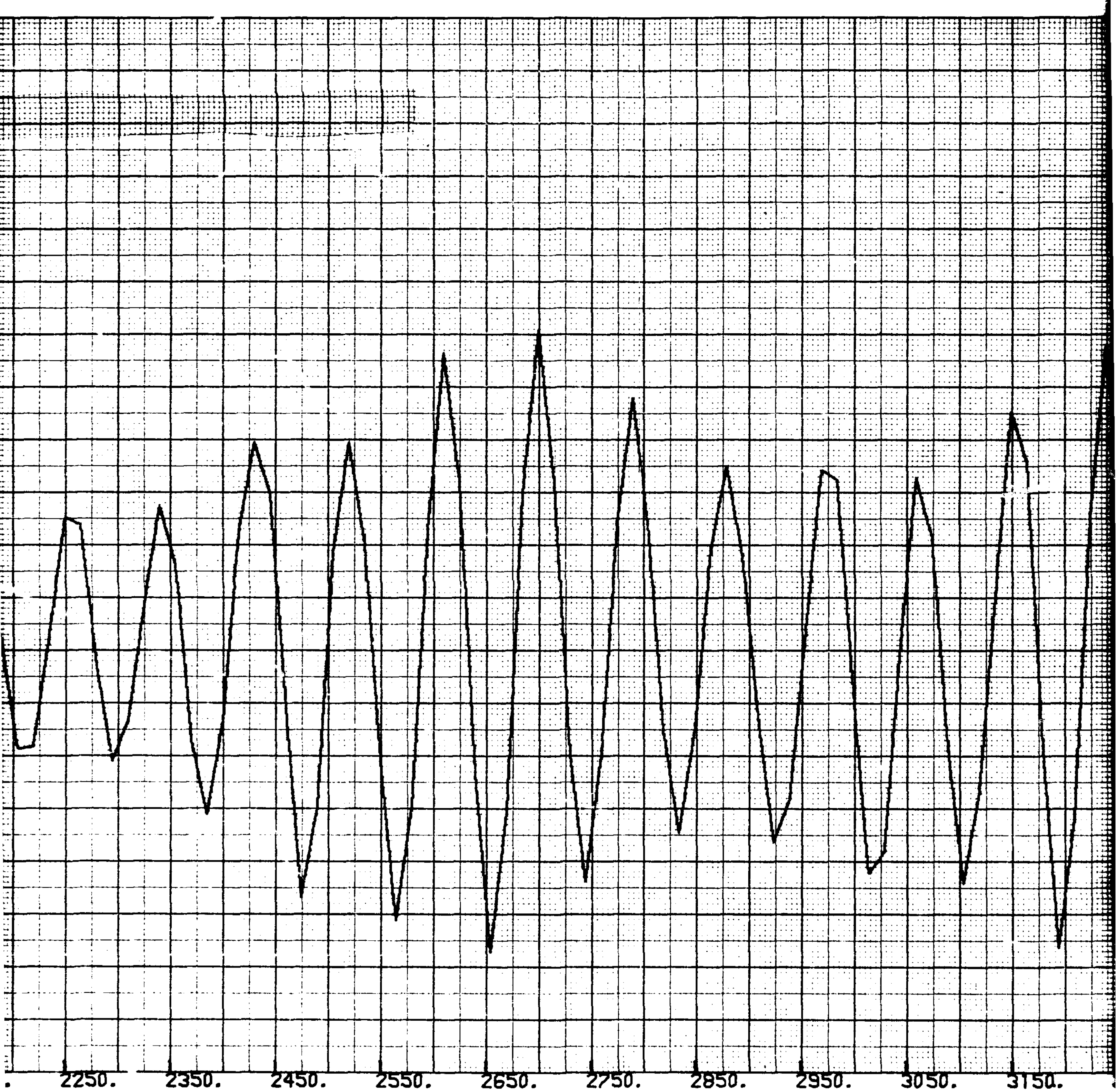

Figure IV-ic. Crosstrack Difference Between "M

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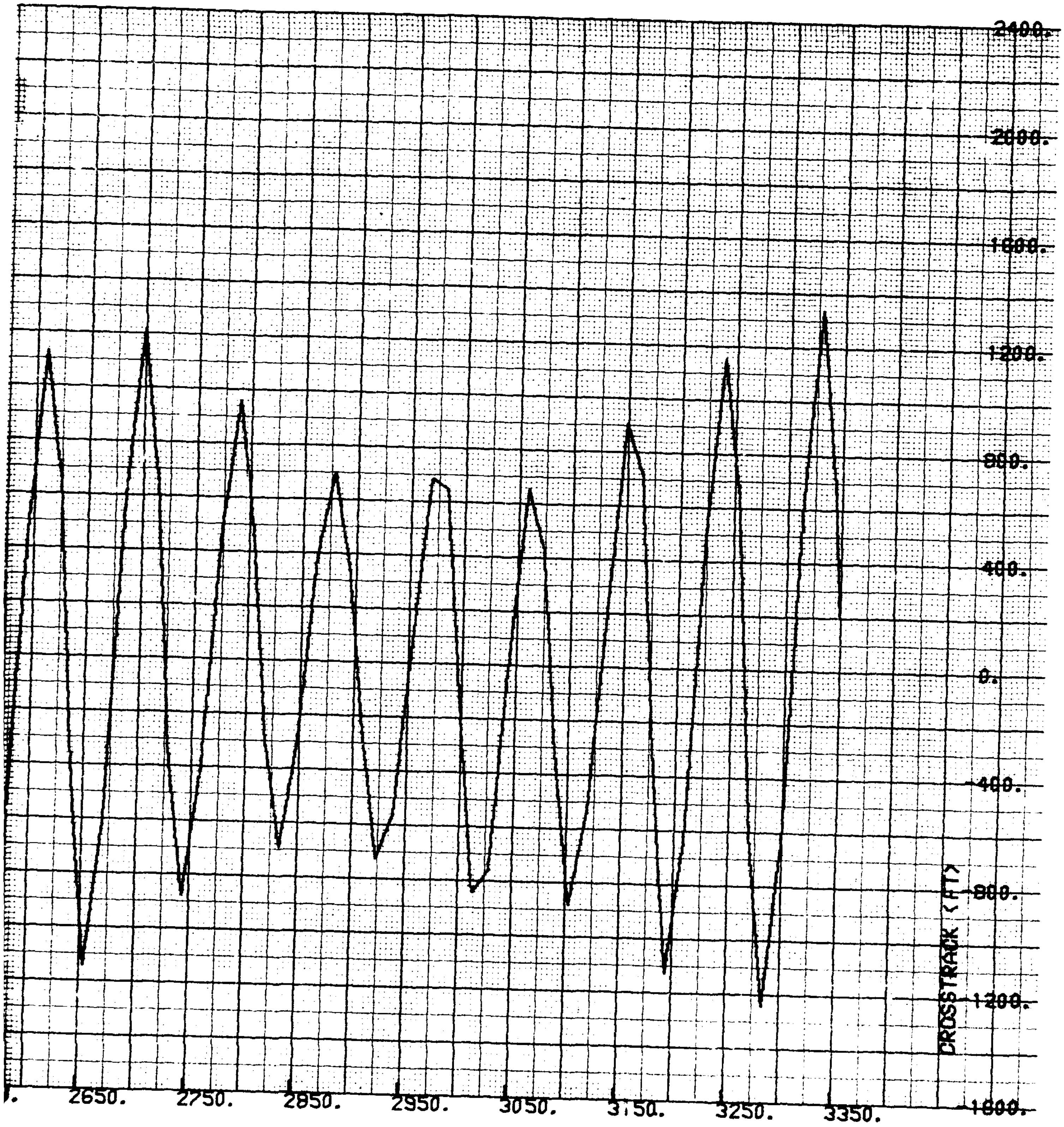

Figure IV-ic. Crosstrack Difference Between "Model" and Reference

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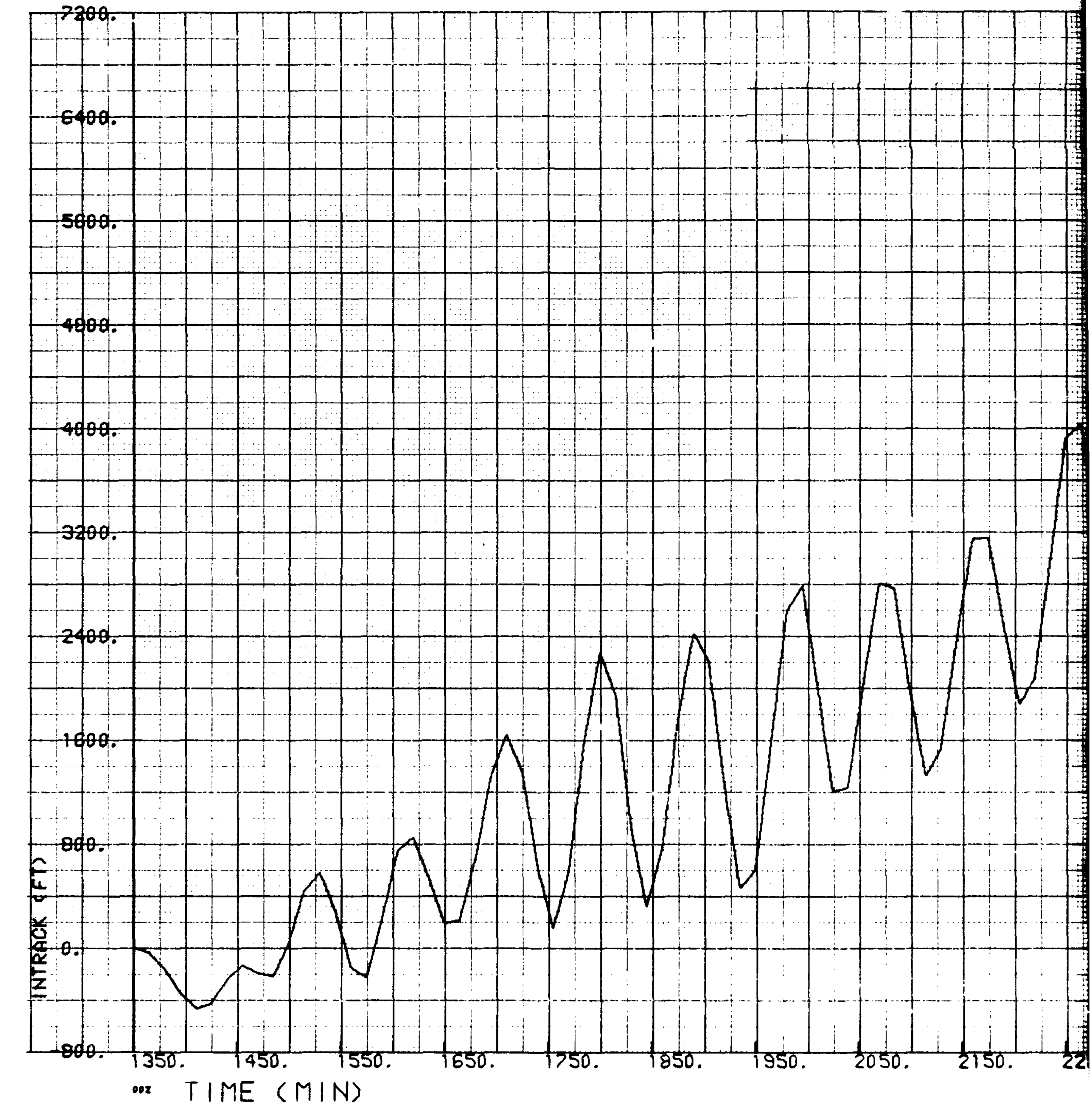

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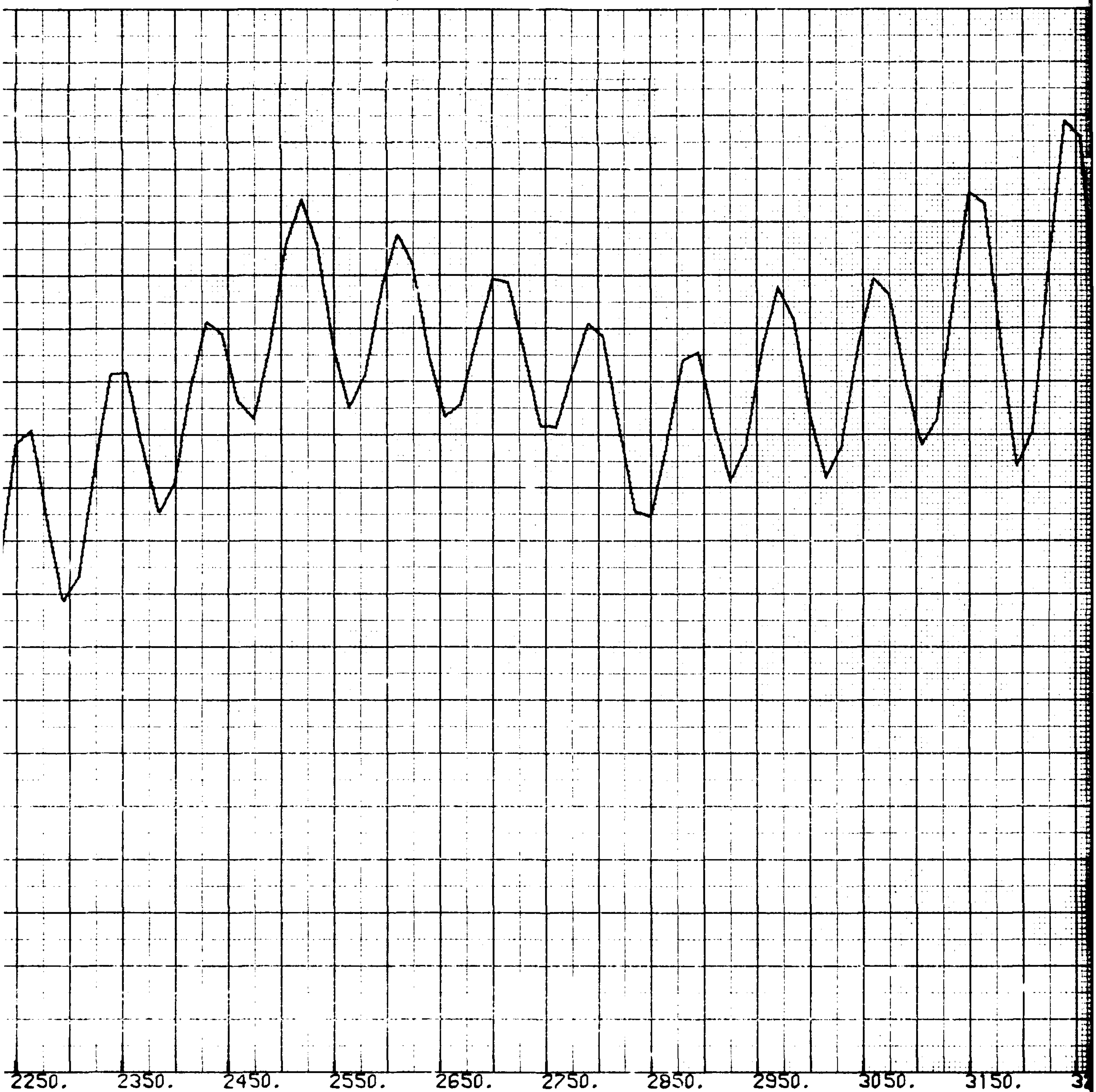


Figure IV-2a. Intrack Difference Getween Referenc
"Real World" Geopotentials

16

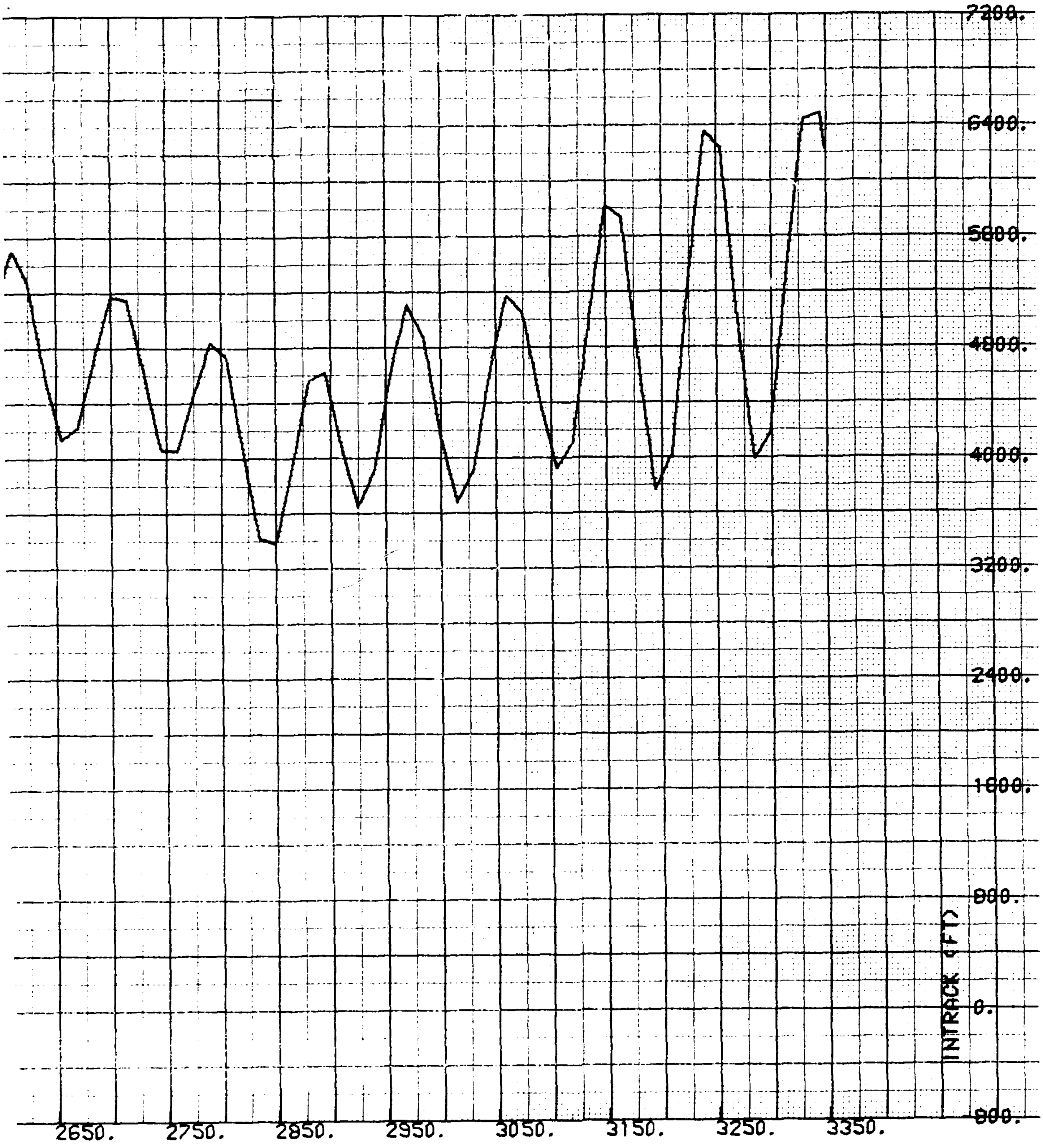
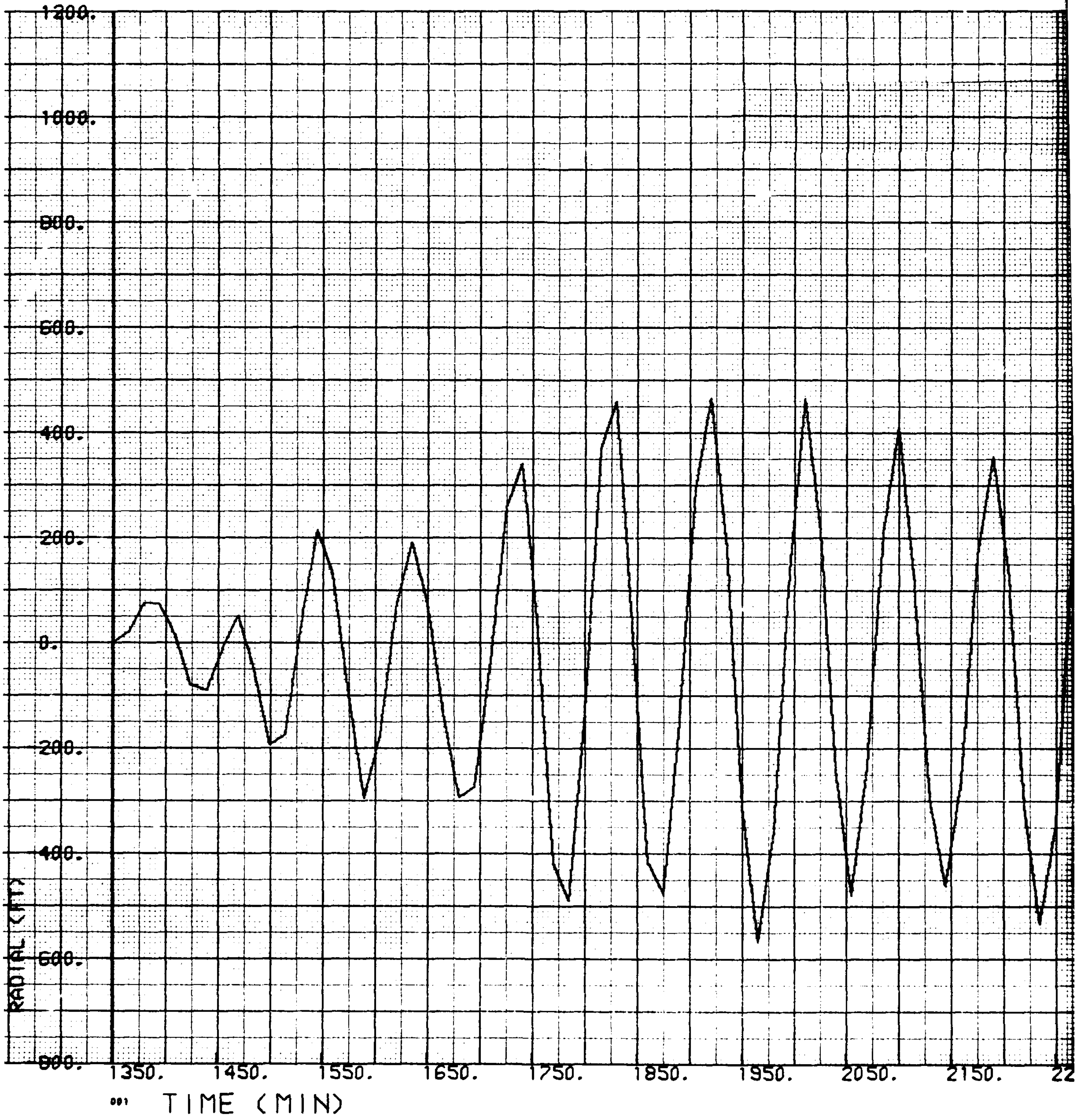


Figure IV-2a. Intrack Difference Getween Reference and "Real World" Geopotentials



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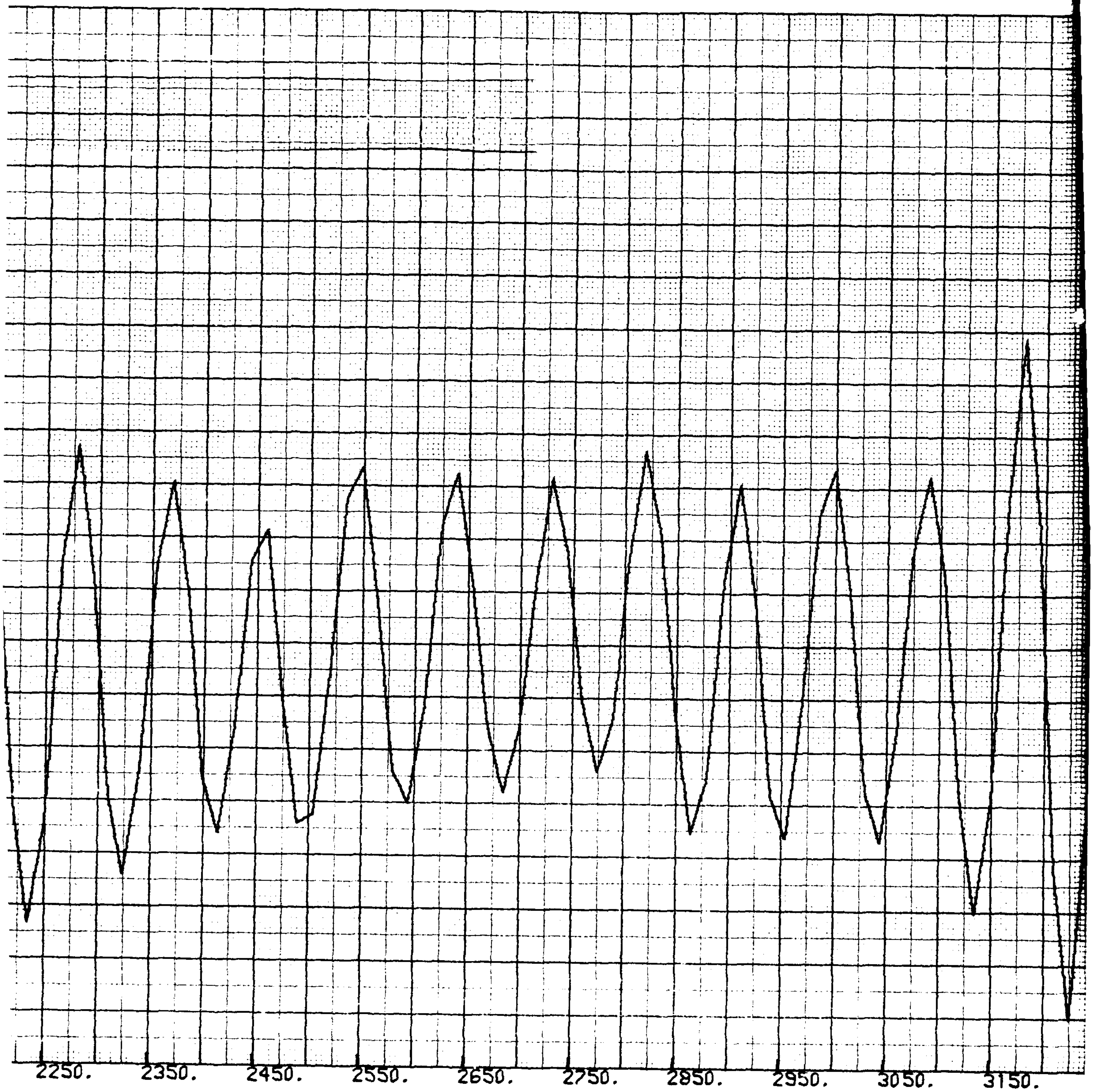

Figure IV-2b. Radial Difference Between Refer
and "Real World" Geopotentials

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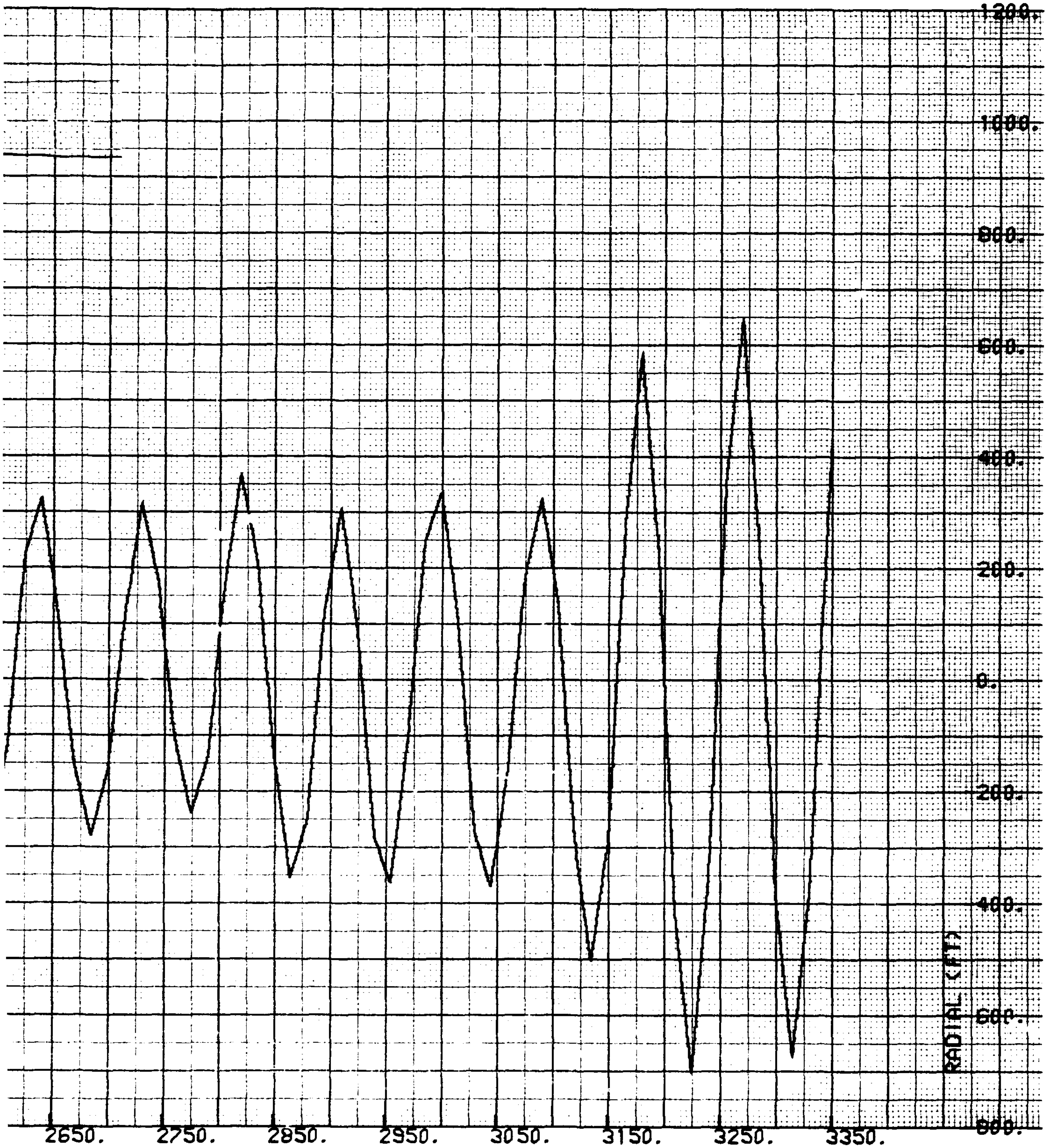
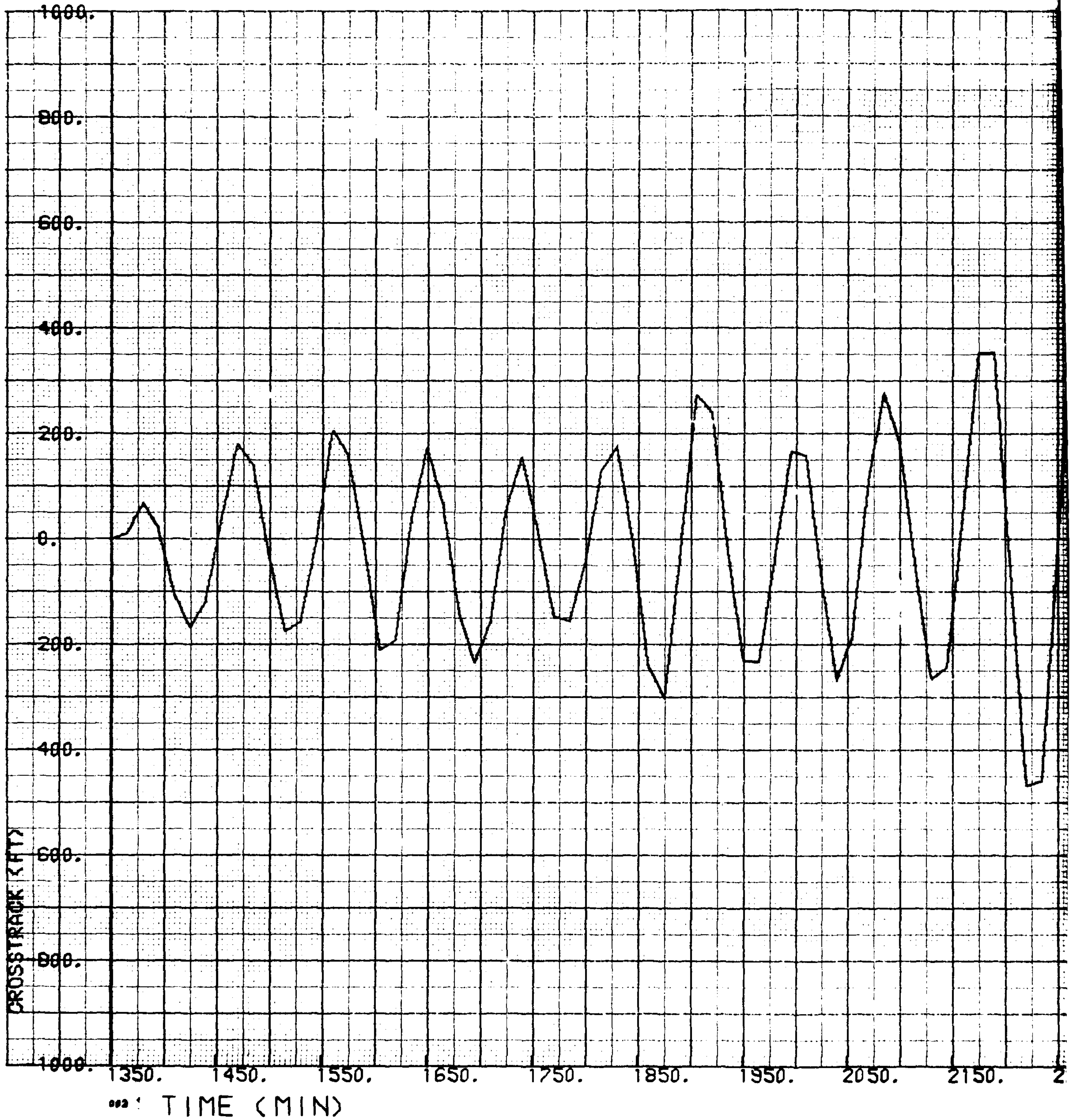


Figure IV-2b. Radial Difference Between Reference and "Real World" Geopotentials

 C



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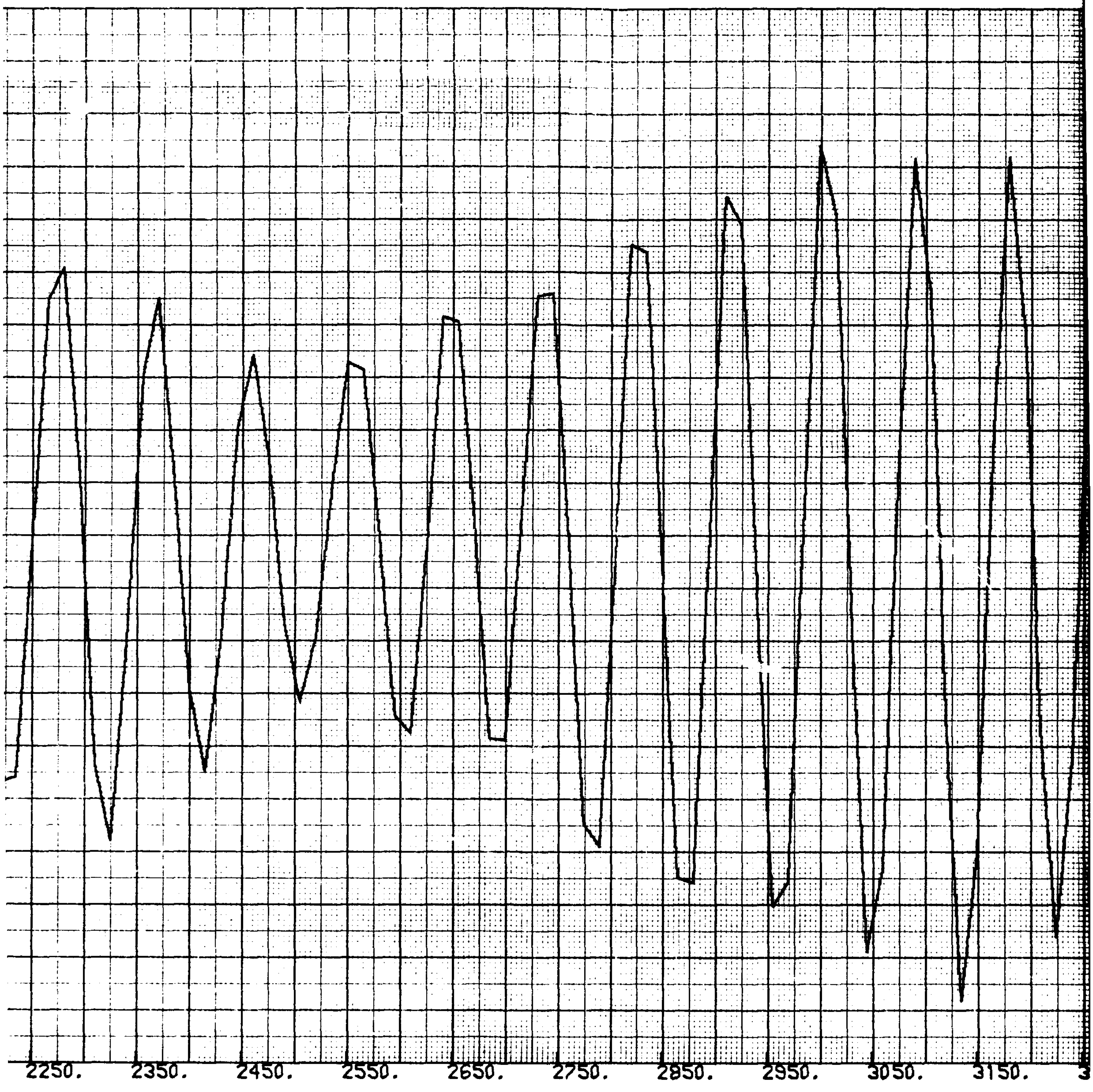

Figure IV-2c. Crosstrack Difference Between Re
and "Real World" Geopotentials

B

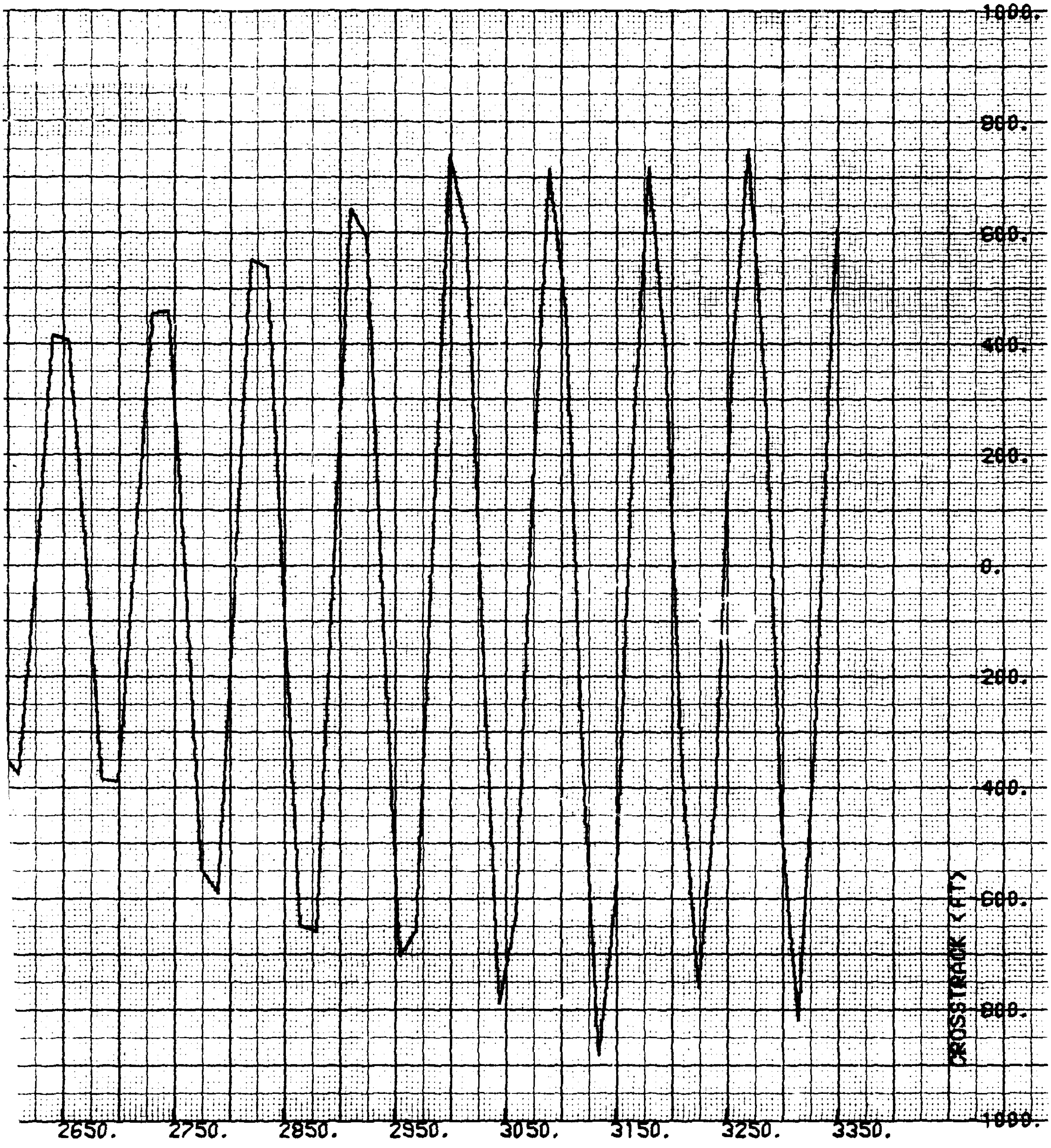

Figure IV-2c. Crosstrack Difference Between Reference
and "Real World" Geopotentials

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SECTION V

"REAL WORLD" DRAG MODEL

To obtain real world atmosphere data, the acceleration profile experienced by the first in a recent series of low altitude satellites to have an on-board low-g accelerometer was utilized. The orbital elements of this density measurement system (DMS) vehicle were quite close to those of the reference orbit. This suggested that the accelerometer data from the DMS - suitably scaled - could be used as an input real world drag profile to the ANS reference vehicle. Approximately 20 revs of continuous DMS data were available for this purpose.

Figure V-1 shows a comparison of the model drag accelerations and the raw DMS sensed accelerations. It is readily seen that their amplitudes do not agree, nor do points of maximum drag in the two sets of acceleration profiles occur at the same time. Approximately 240 sec of data was dubbed on the front of the DMS data and a multiplier, determined by the ratio of the total time spans, was then applied to the result to force alignment of the points of maximum drag. Since the orbital periods were very nearly equal, the multiplier was quite close to 1, specifically 0.99770736. This resulted in the situation depicted in Figure V-2.

If this data were used directly for real world drag acceleration without further scaling, it is possible that the resulting integrated real world ephemeris would have times of perigee passage out of phase with the times of maximum drag force. Also, the magnitude of the perigee drag acceleration itself might have appeared unreasonable in the absence of any scaling. To prevent this from occurring, the amplitude of the data was scaled so the real world energy loss would be the same as that of the model. Specifically, the energy loss is directly proportional to the velocity loss

$$\Delta V = \int a_D \, dt$$

where a_D is the drag acceleration.

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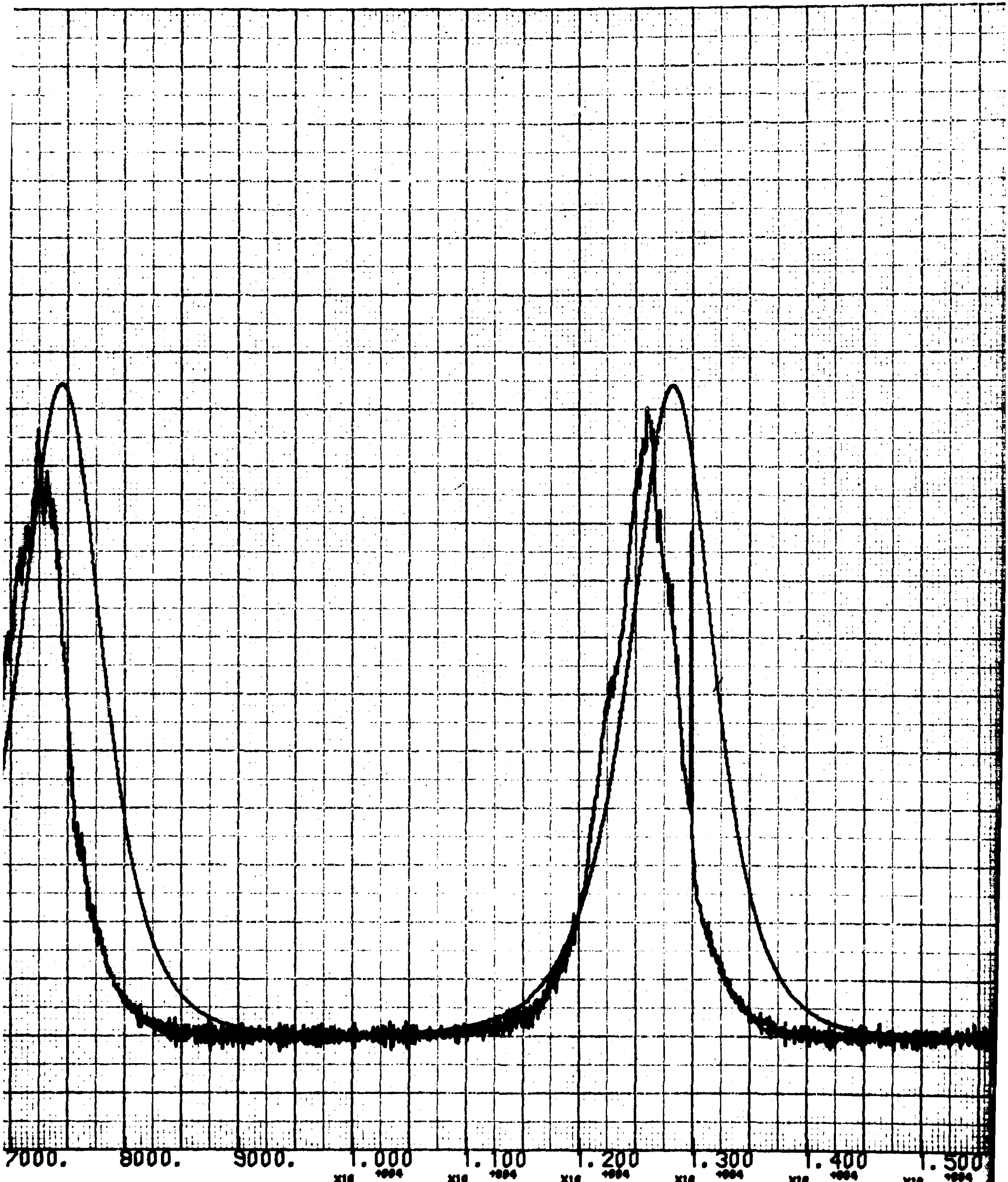
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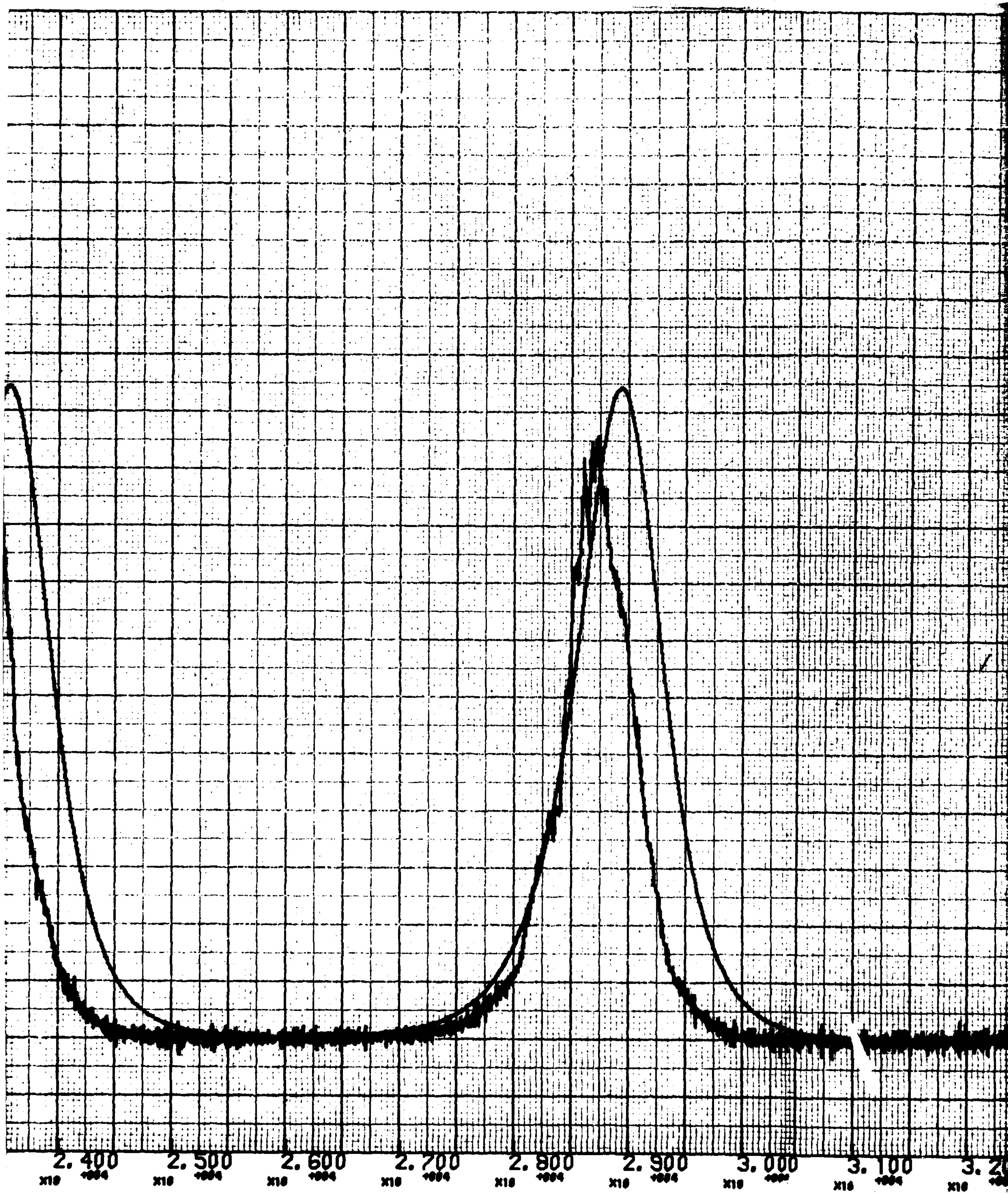
2.400 X10 +004
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3.100 X10 +004

D

Figur

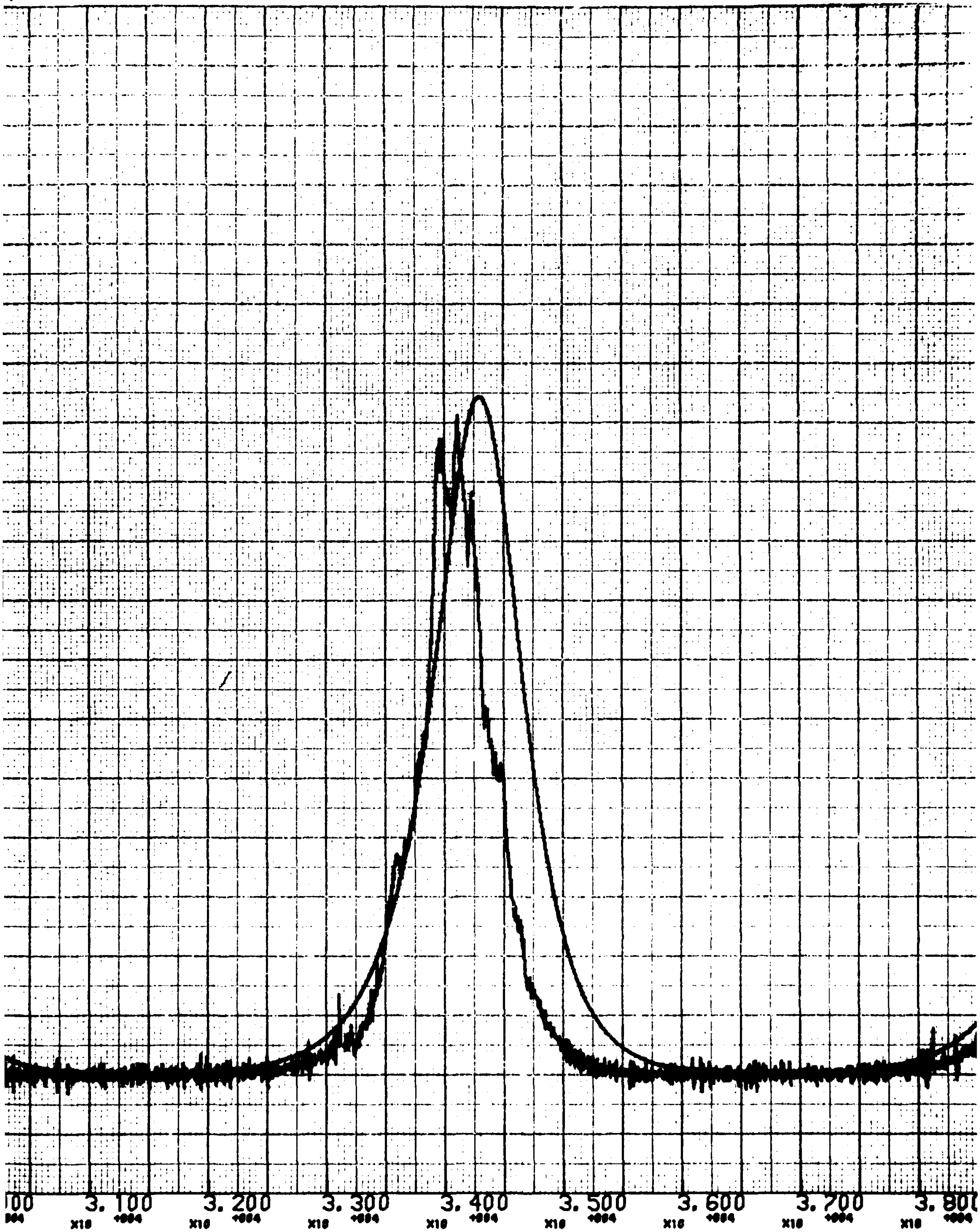
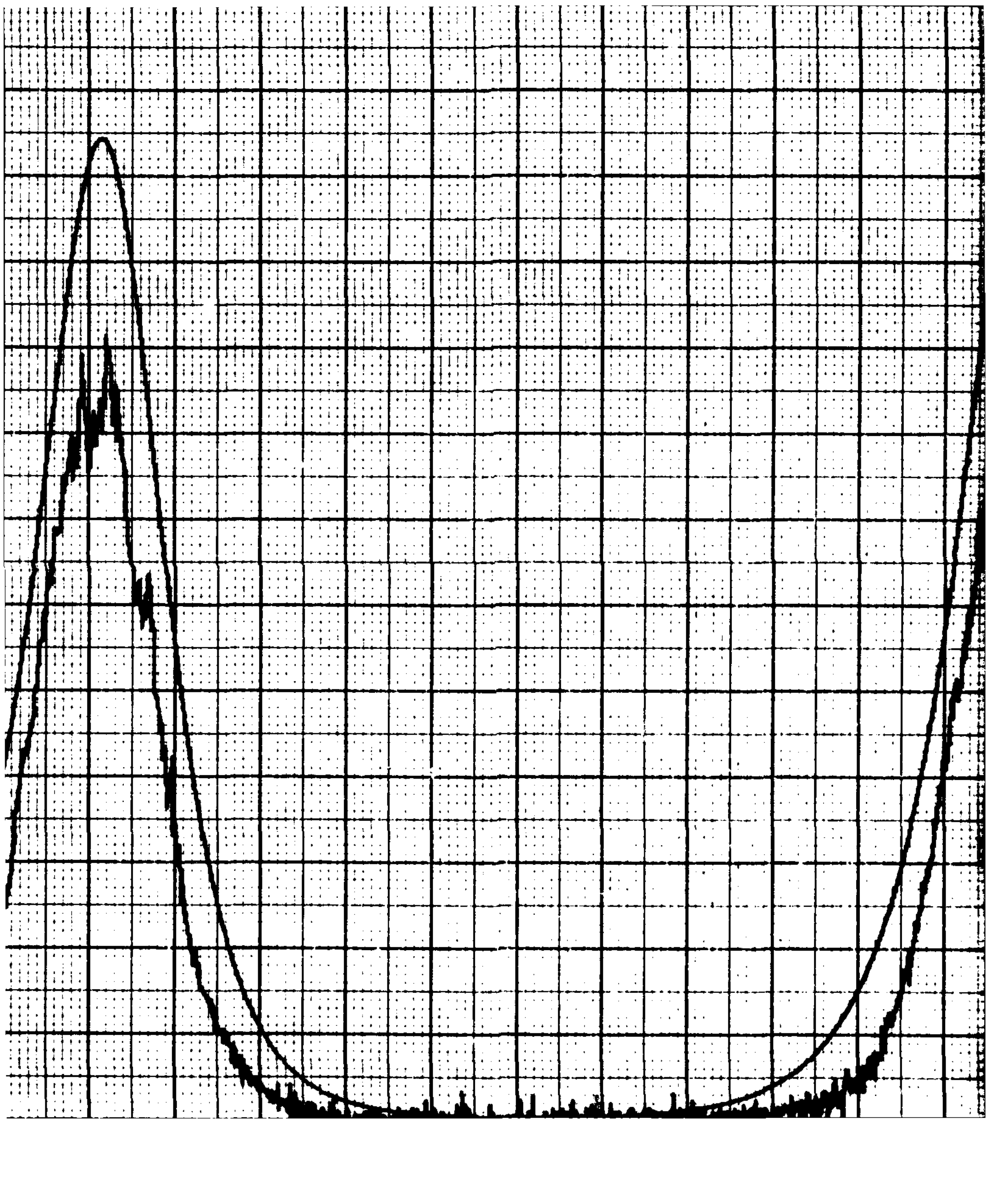
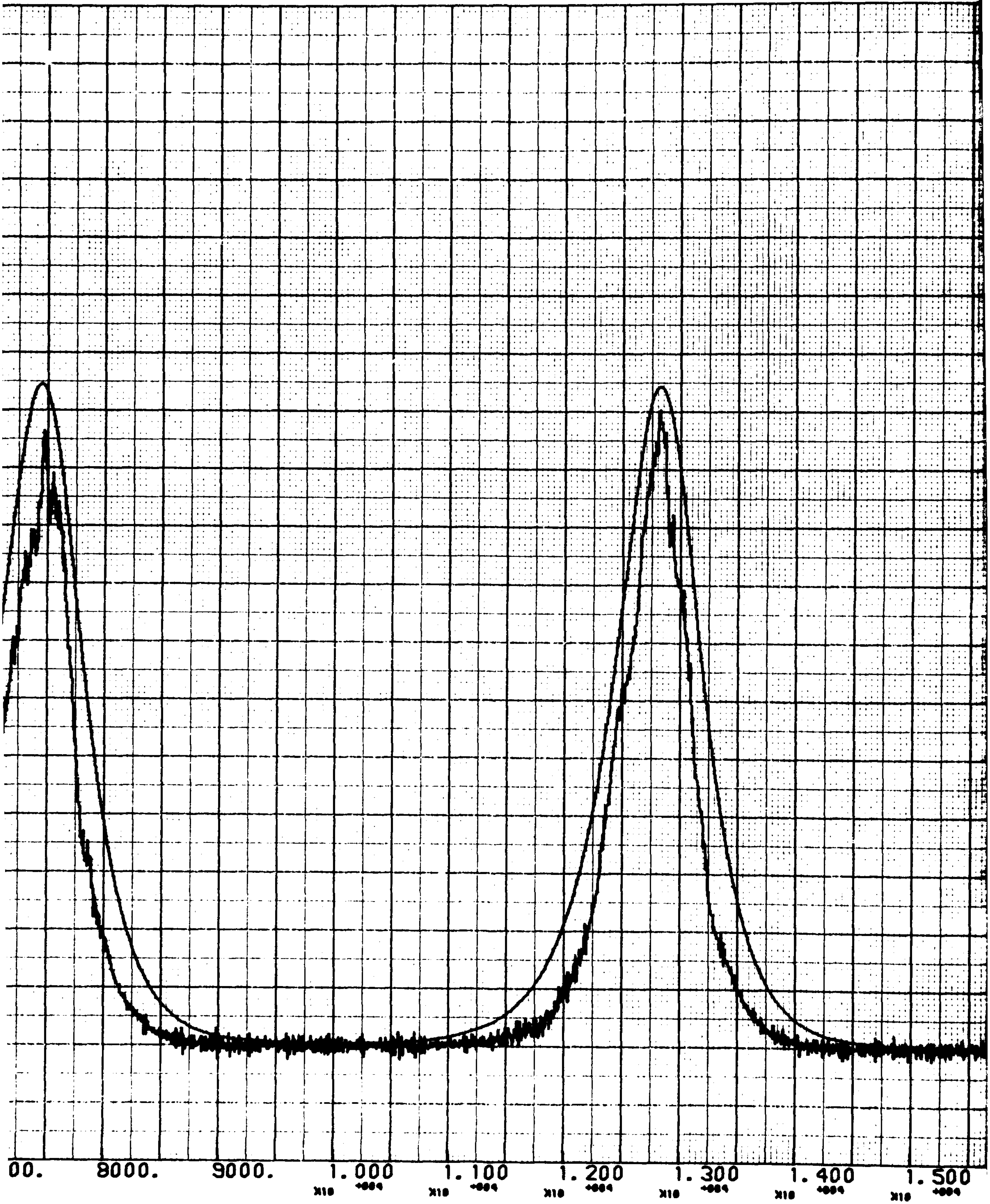


Figure V-1. Raw DMS Data and "Model" Drag Data

E

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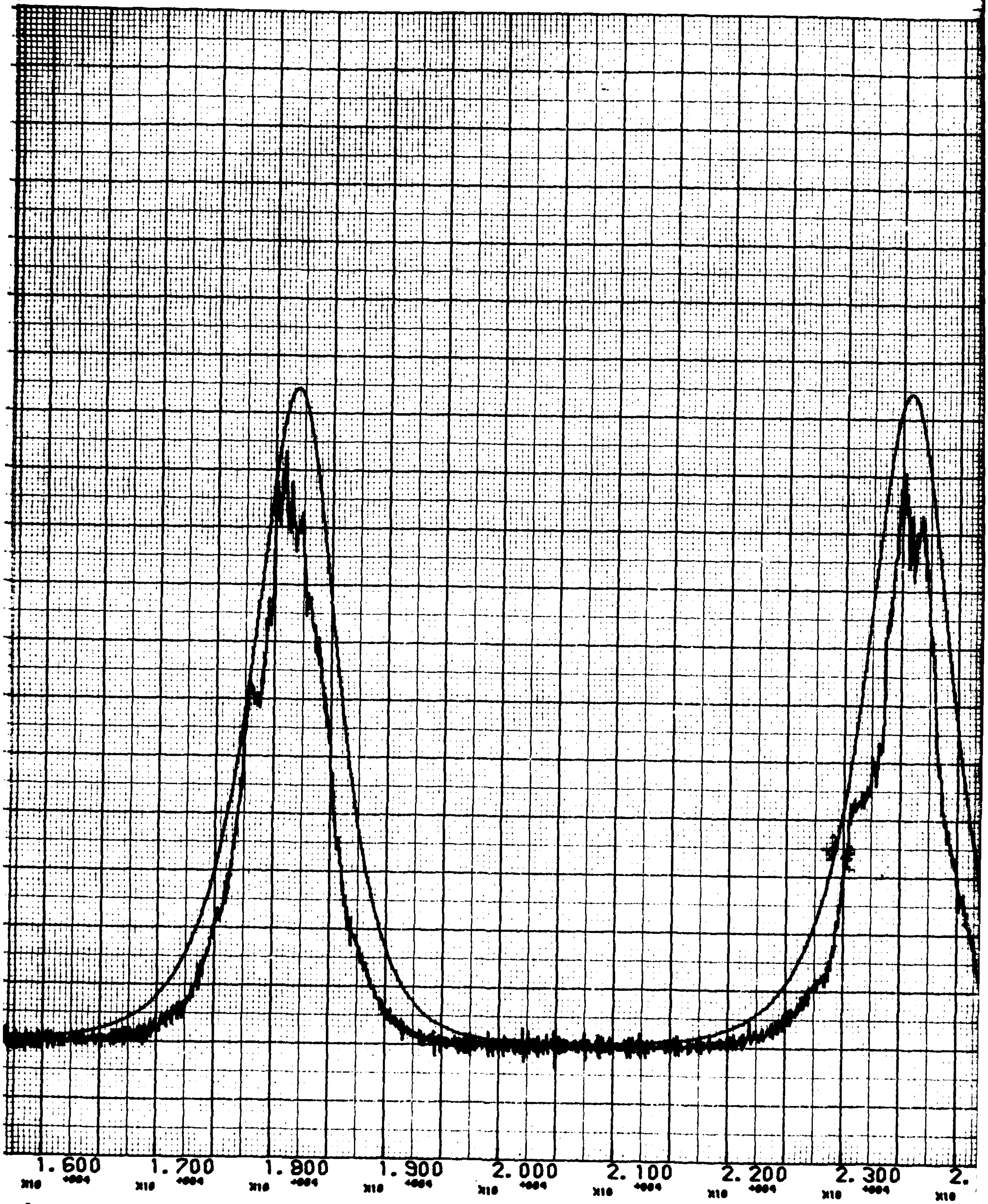
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X10

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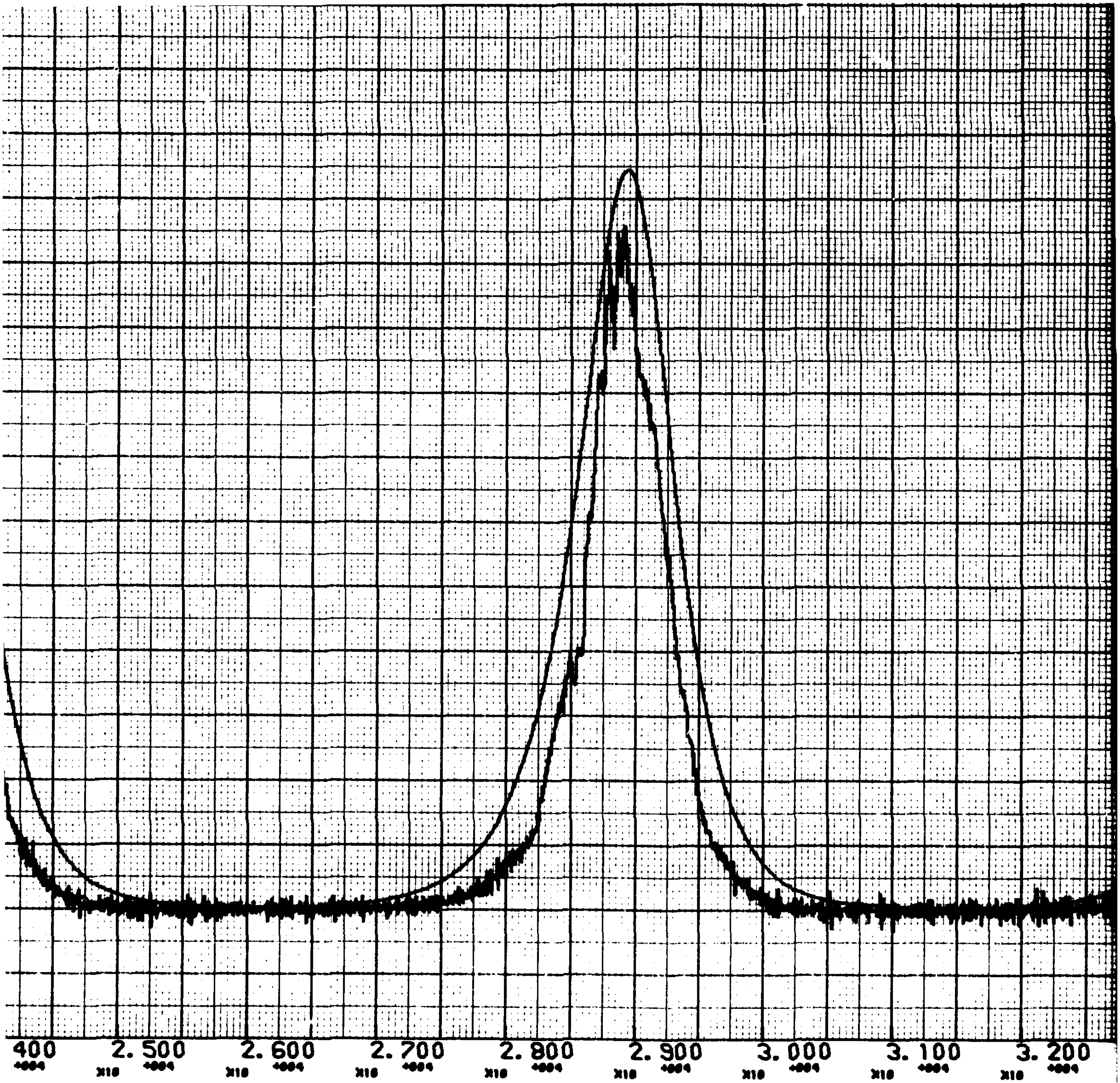
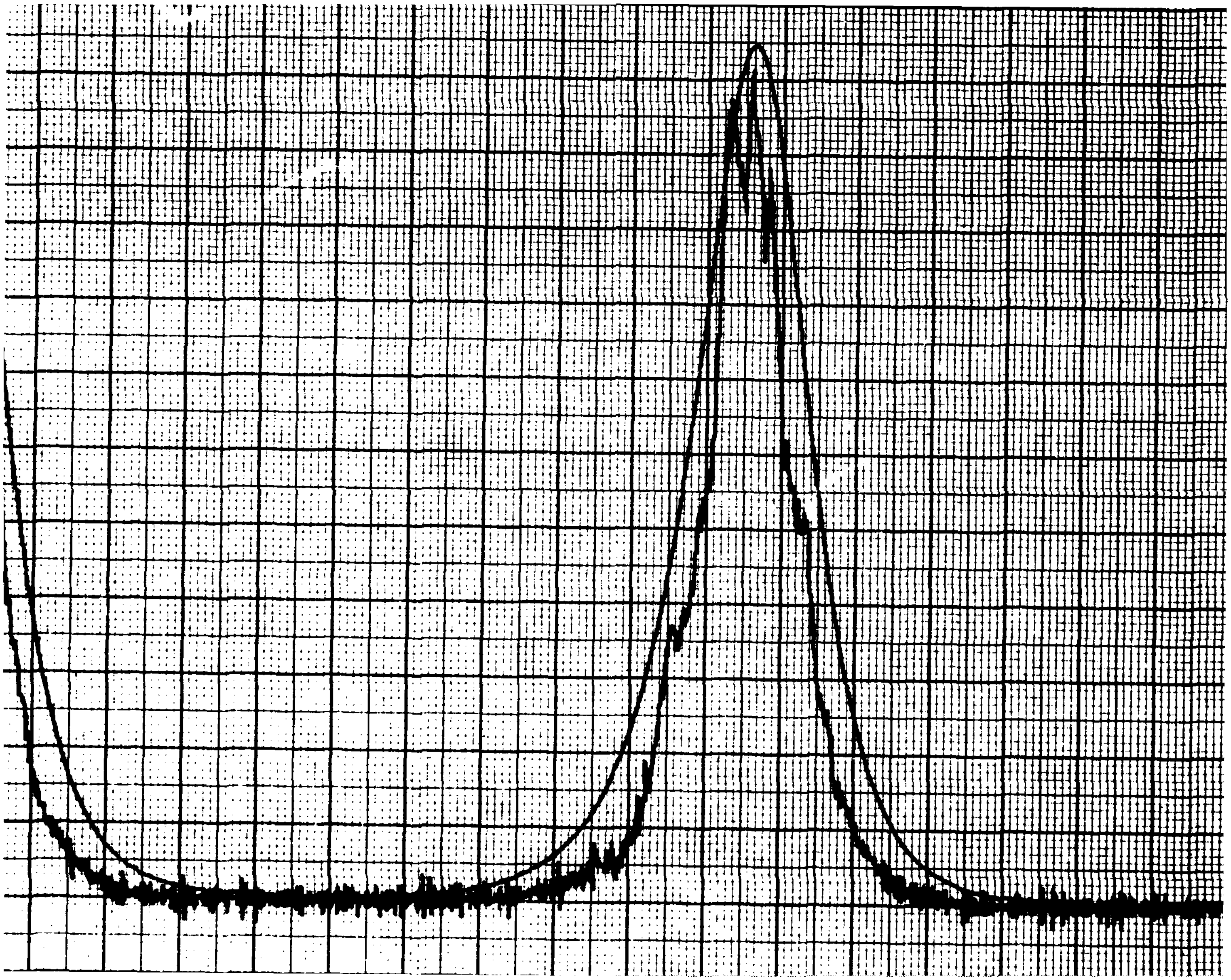


D

Figure V-2. DMS D



The accelerometer data scaling was done two different ways. In the generation of the real world atmosphere data reported on herein, the energy loss, or ΔV, was preserved on a rev-to-rev basis. A second candidate real world ephemeris was also generated in which the total 20-rev ΔV was preserved instead.

The slight differences between the two real world ephemerides using rev-to-rev ΔV scaling and 20-rev ΔV scaling were considered negligible and the former case was chosen, albeit somewhat arbitrarily, to be the real world drag profile for this study. Although the DMS vehicle's perigee was about 73 n mi, it had a lower ballistic coefficient (0.008 ft^2/lb) than that chosen for the reference vehicle (0.02 ft^2/lb). As a result, the rev-by-rev velocity loss for the DMS flight was less than that for the reference orbit. Each rev of the DMS data was scaled by the ratio

$$\frac{\Delta V \text{ loss reference}}{\Delta V \text{ loss DMS}}$$

which is a number greater than 1. Figure V-3 compares the now-normalized DMS data with the model drag profile. Each rev of both orbits imparts the same energy loss to the vehicle, but the real world drag at any given point within a rev generally differs from that of the model. As Figure V-3 shows, it would be extremely difficult to reproduce the normalized DMS acceleration profile with an atmosphere model.

The normalized DMS drag profile was written on tape in a format suitable for use as an accelerometer input to TRACE.

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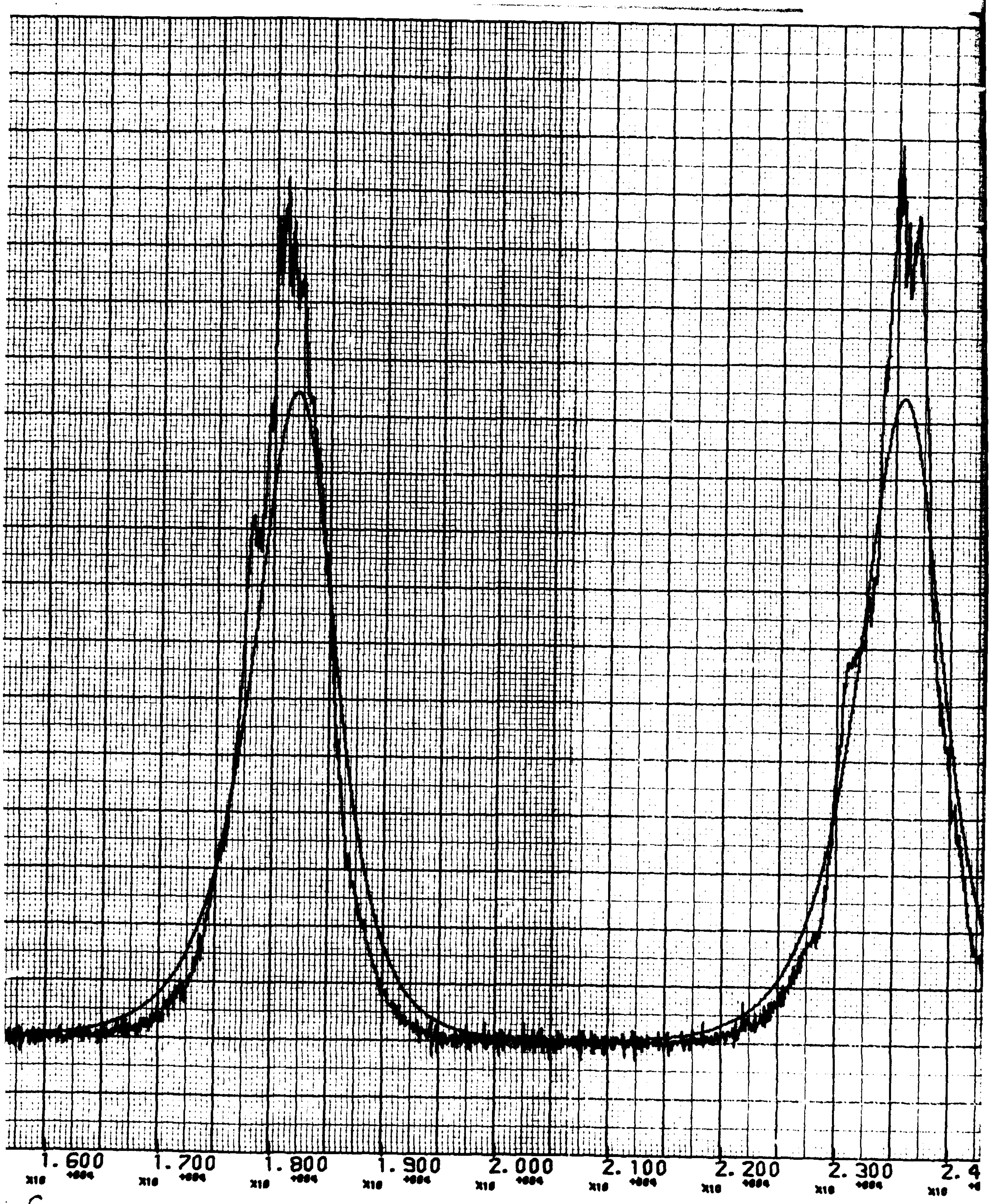

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1.800
X10 +004
1.900
X10 +004
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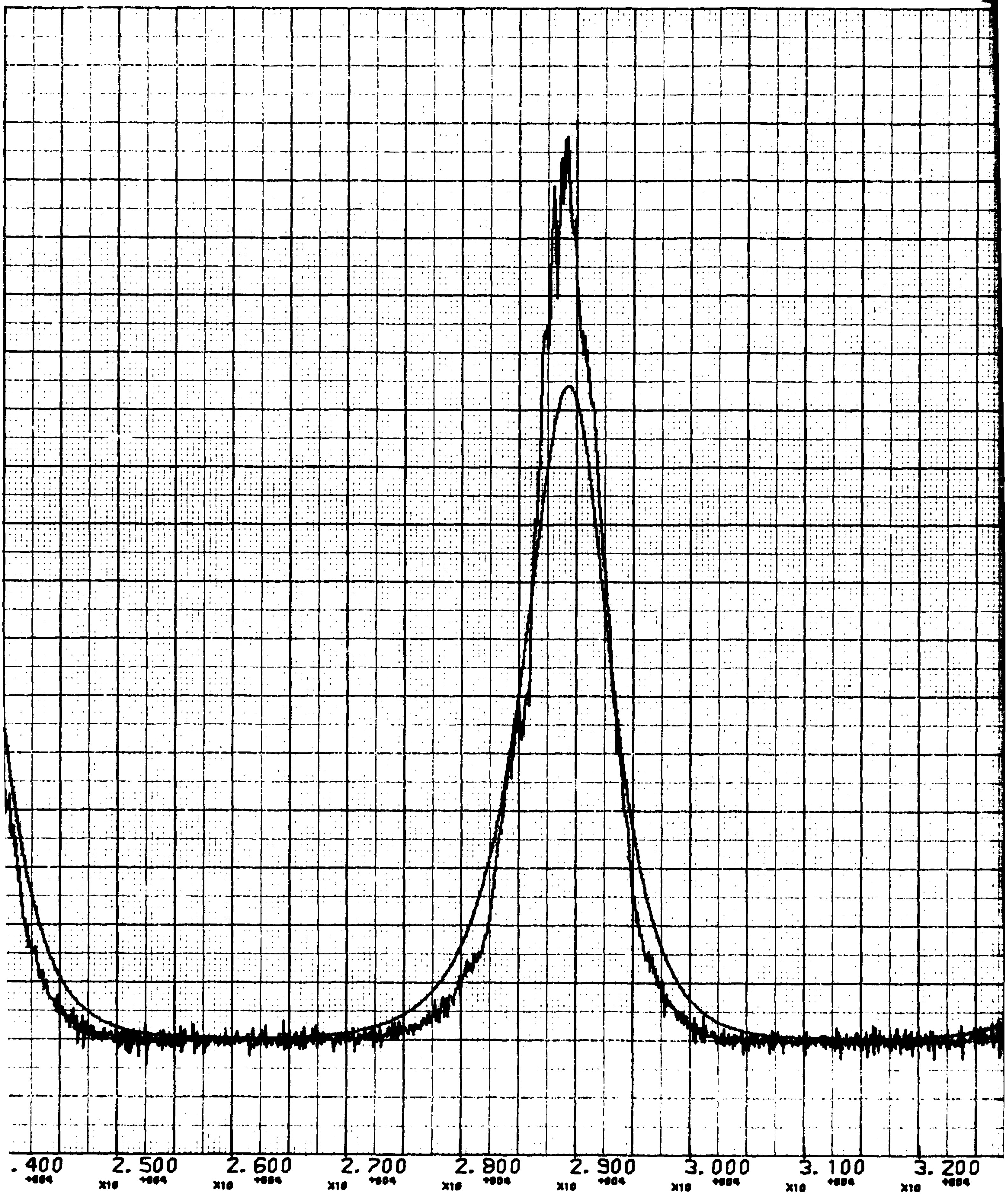

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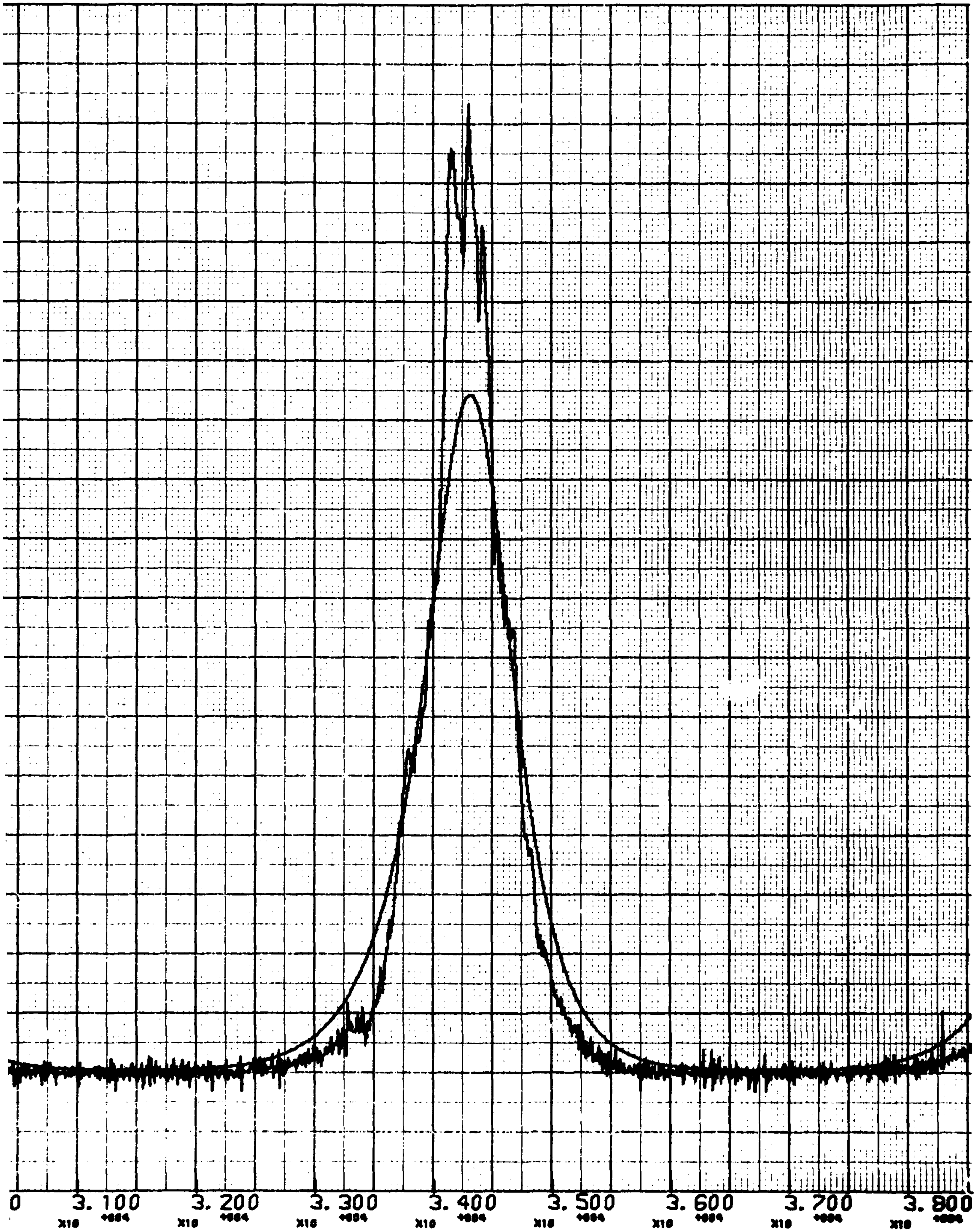
Figure V-



E

Figure V-3. DMS Data; Scaled Rev-by-Rev

SECTION VI

"REAL WORLD" EPHEMERIS

The geopotential described in Section IV and the accelerometer drag profile described in Section V were used as force models together with the initial conditions described in Section II. The gravitational attractions of the sun and moon were also included to make the real world ephemeris as near to the real world as possible. The integration was carried out over the same 20 revs as the model case.

Since the real world drag impulse was forced to agree on a rev-to-rev basis with the model drag impulse, the nodal crossing times and positions for the real world ephemeris should be close to those of the model ephemeris. Table VI-1 contains (in the same format as Table II-2) these conditions for the real world ephemeris.

A computer listing of the ephemeris for the first two revs is included in Appendix B.

Table VI-1. Nodal Conditions for "Real World" Ephemeris

Node	Nodal Crossing Time (Mo/Day/Yr, Hr/Min/Sec)	Position XYZ (ft)	Velocity $\dot{X}\dot{Y}\dot{Z}$ (fps)
0	2/29/80 22/30/0.0	-1.59387495E+7 1.51831715E+7 3.84199432E-15	6.16441283E+3 6.00674669E+3 2.36312409E+4
1	2/29/80 23/59/34.86323	-1.59847865E+7 1.51293060E+7 -4.34333501E-4	6.14523022E+3 6.02755269E+3 2.36341645E+4
2	3/1/80 1/29/9.07663	-1.60300679E+7 1.50750883E+7 -9.00100265E-4	6.12585377E+3 6.04795515E+3 2.36378708E+4
3	3/1/80 2/58/42.47044	-1.60754250E+7 1.50202680E+7 -3.72571321E-4	6.10597427E+3 6.06962440E+3 2.36415889E+4
4	3/1/80 4/28/15.08251	-1.61214667E+7 1.49650787E+7 7.13800964E-5	6.08564728E+3 6.09052957E+3 2.36449662E+4
5	3/1/80 5/57/47.03614	-1.61672548E+7 1.49094396E+7 -1.45264228E-3	6.06617102E+3 6.11093468E+3 2.36485783E+4
6	3/1/80 7/27/18.19338	-1.62122626E+7 1.48540354E+7 2.97112782E-5	6.04648130E+3 6.13218703E+3 2.36522571E+4
7	3/1/80 8/56/48.50253	-1.62571392E+7 1.47988953E+7 -1.44689247E-3	6.02720411E+3 6.15384146E+3 2.36551901E+4
8	3/1/80 10/26/17.98143	-1.63017930E+7 1.47434625E+7 -9.23928079E-5	6.00754997E+3 6.17519473E+3 2.36584412E+4
9	3/1/80 11/55/46.64434	-1.63463189E+7 1.46883472E+7 -1.65842335E-3	5.98752310E+3 6.19610495E+3 2.36615671E+4

Table VI-1. Nodal Conditions for "Real World" Ephemeris (Continued)

Node	Nodal Crossing Time (Mo/Day/Yr, Hr/Min/Sec)	Position XYZ (ft)	Velocity $\dot{X}\dot{Y}\dot{Z}$ (fps)
10	3/1/80 13/25/14.56680	-1.63910809E+7 1.46329058E+7 -3.17691850E-4	5.96715899E+3 6.21640000E+3 2.36645896E+4
11	3/1/80 14/54/41.66063	-1.64355506E+7 1.45773503E+7 -2.74429165E-4	5.94617177E+3 6.23661260E+3 2.36677299E+4
12	3/1/80 16/24/8.03161	-1.64803676E+7 1.45214059E+7 -1.76019997E-3	5.92479582E+3 6.25703989E+3 2.36702724E+4
13	3/1/80 17/53/33.60059	-1.65248092E+7 1.44654088E+7 1.48863718E-4	5.90404820E+3 6.27813694E+3 2.36727759E+4
14	3/1/80 19/22/58.32904	-1.65687151E+7 1.44090721E+7 2.95331619E-6	5.88415436E+3 6.29922478E+3 2.36757447E+4
15	3/1/80 20/52/22.17168	-1.66122750E+7 1.43525901E+7 -2.52707804E-4	5.86433410E+3 6.32034803E+3 2.36787538E+4
16	3/1/80 22/21/45.07135	-1.66551805E+7 1.42959754E+7 -9.01314653E-4	5.84432969E+3 6.34130557E+3 2.36821387E+4
17	3/1/80 23/51/7.11635	-1.66982314E+7 1.42396118E+7 -1.36532782E-3	5.82390063E+3 6.36152469E+3 2.36851197E+4
18	3/2/80 1/20/28.39917	-1.67405388E+7 1.41829899E+7 -1.33762579E-3	5.80307017E+3 6.38107658E+3 2.36889368E+4
19	3/2/80 2/49/48.79290	-1.67827649E+7 1.41258533E+7 -9.02900611E-4	5.78157663E+3 6.40182983E+3 2.36928140E+4
20	3/2/80 4/19/8.28148	-1.68255872E+7 1.40682145E+7 -9.47885195E-4	5.75967552E+3 6.42207719E+3 2.36964598E+4

SECTION VII

COMPARISONS OF "MODEL" AND "REAL WORLD" EPHEMERIDES

A trajectory difference run, similar to those described in Section IV, was made for the model and the real world ephemerides. Figures VII-1a, b, and c depict the radial, in-track, and cross-track differences, respectively. The radial difference plot shows a 1-rev periodicity whose amplitude grows with time to approximately 3300 ft by rev 20. The in-track difference plot also shows a 1-rev periodicity with maximum amplitude about 5000 ft and a secular term which grows about 750 ft/rev. Much of this secular growth can be attributed to the differences in GM between the two geopotentials (the model GM is 1.4076538841E+16 ft^3/sec^2, while the real world GM is 1.4076468597E+16 ft^3/sec^2). The cross-track difference plot shows a clear 1-rev periodicity and modulation at some multiple number of revs. The maximum amplitude is about 800 ft; no secular growth is discernible.

To further illustrate the differences between the model and real world ephemerides, the latitude, longitude, and altitude at selected perigees throughout the 20-rev span are shown in Table VII-1.

From the foregoing, it is reasonable to conclude that the real world ephemeris is in a sense representative of the real world. It is probably not as complex as the actual real world, but it is sufficiently more complex than an ephemeris generated by conventional models for the purpose at hand. The difference run just discussed indicates that the real world ephemeris could not readily be reproduced by conventional modeling techniques.

The content and format of the final data tape delivered to contractors is discussed in Appendix C.

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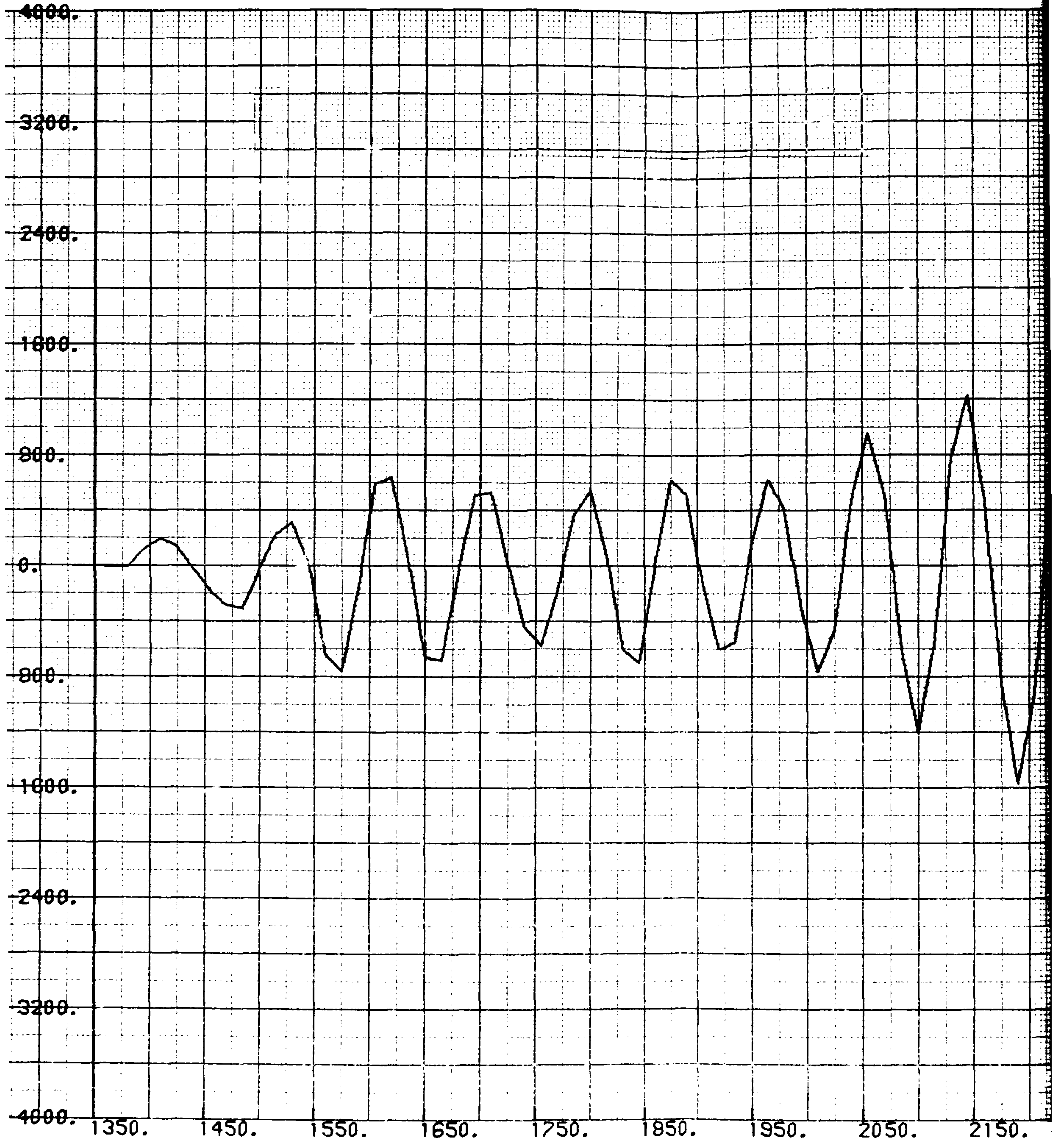

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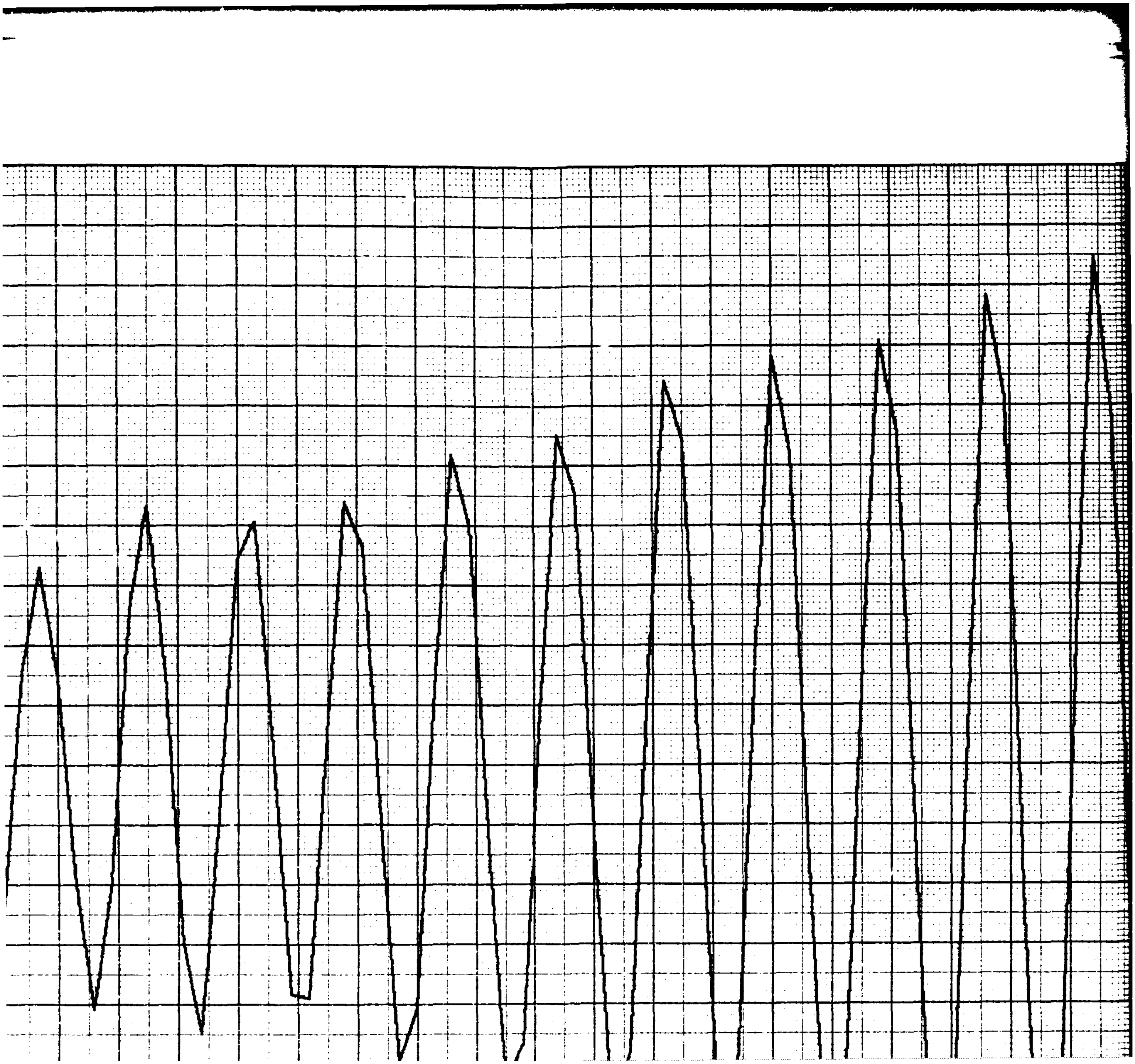


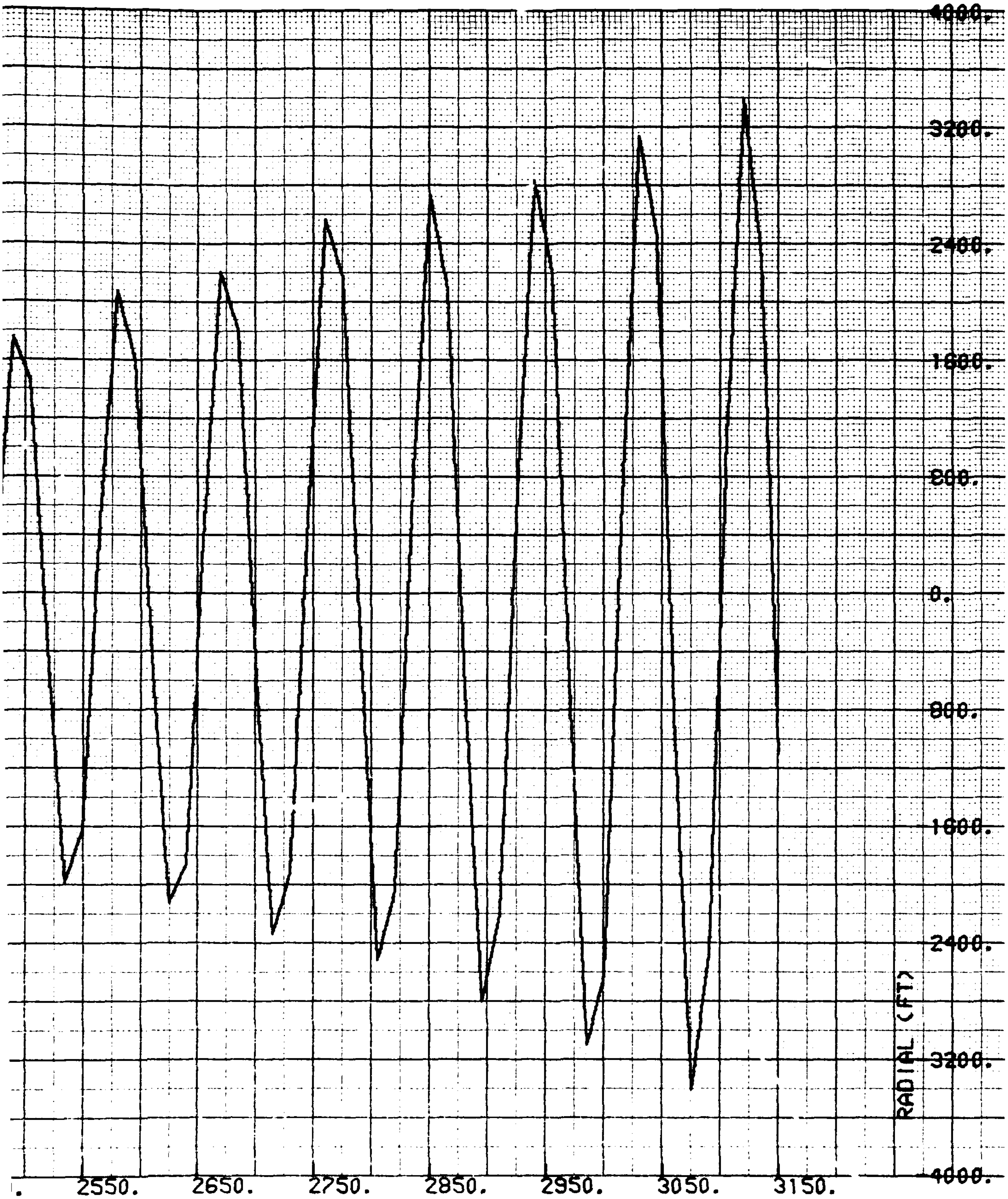
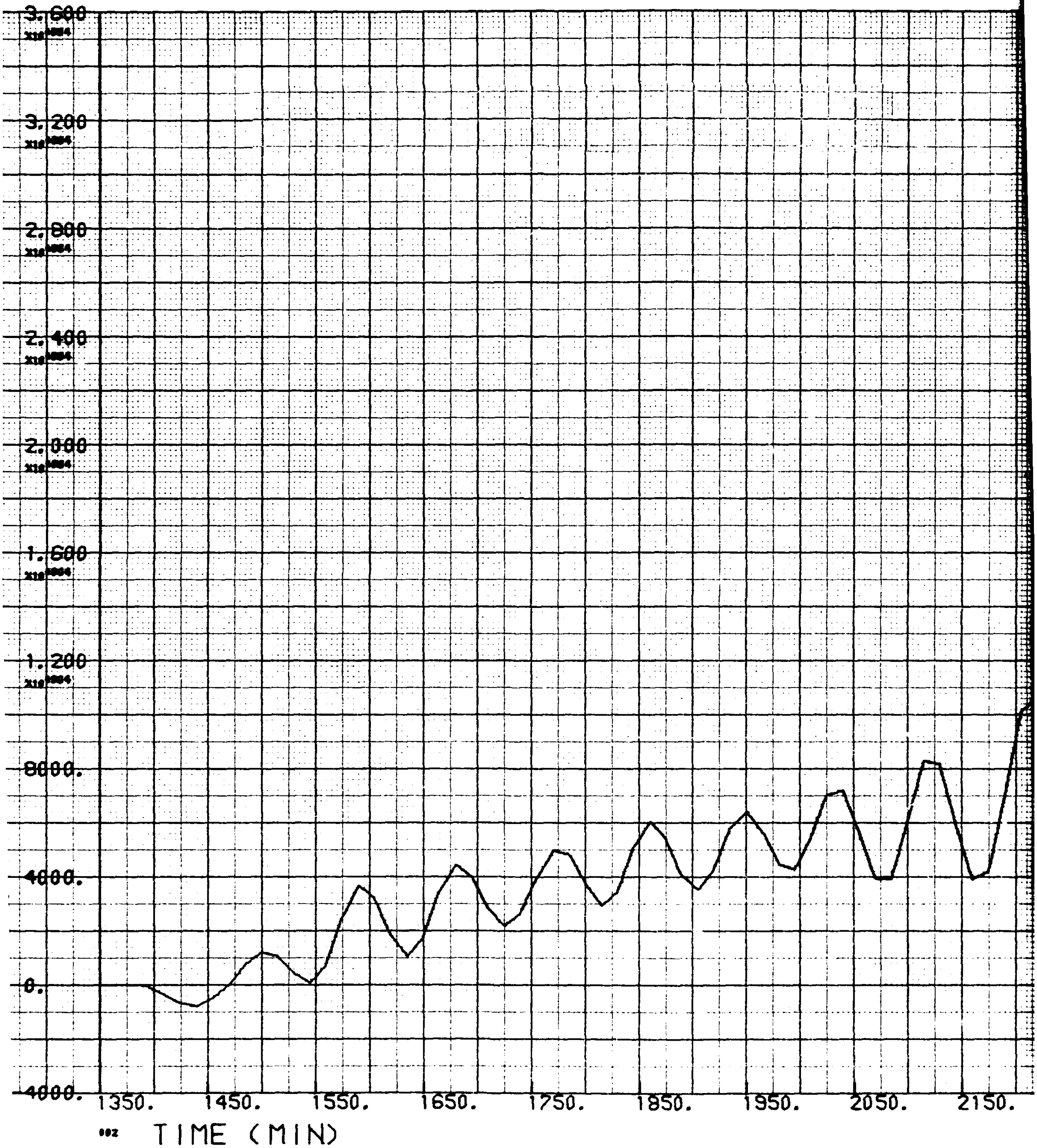


Figure VII-ia. Radial Difference Between "Model" Ephemeris and "Real World" Ephemeris



3.600 x10^004
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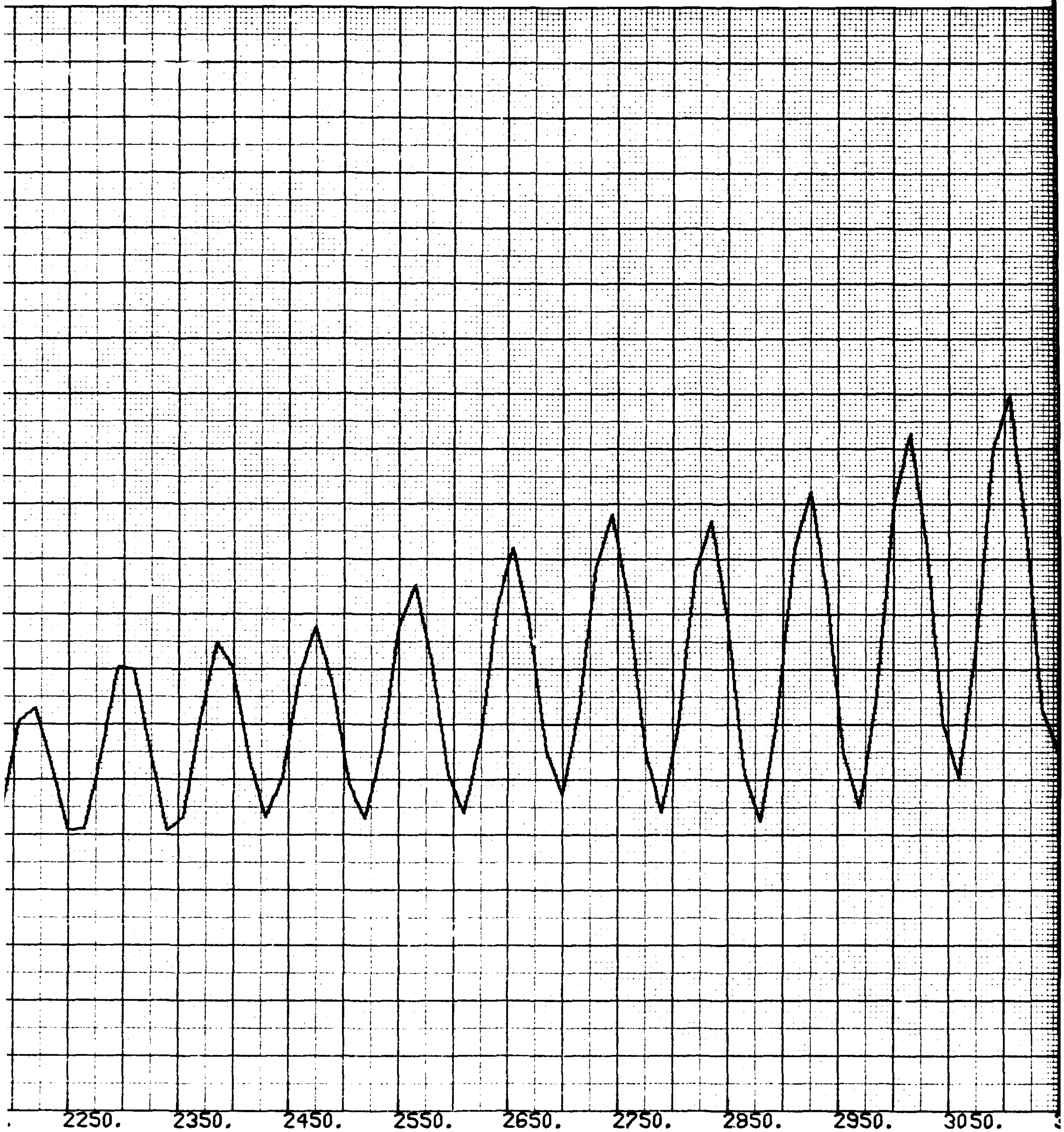

Figure VII-ib. Intrack Difference Between "Model" Ephen
and "Real World" Ephemeris

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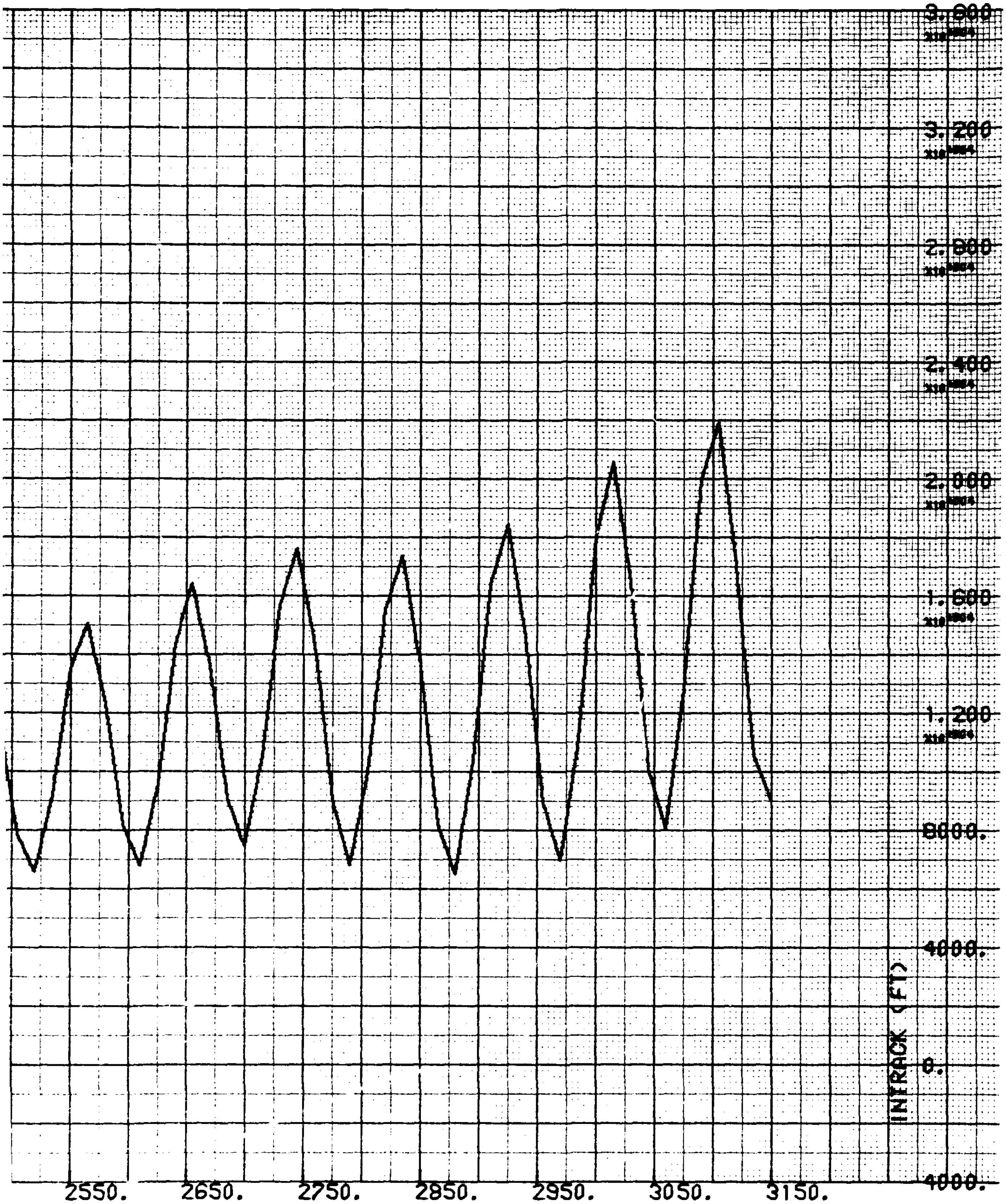

Figure VII-ib. Intrack Difference Between "Model" Ephemeris and "Real World" Ephemeris

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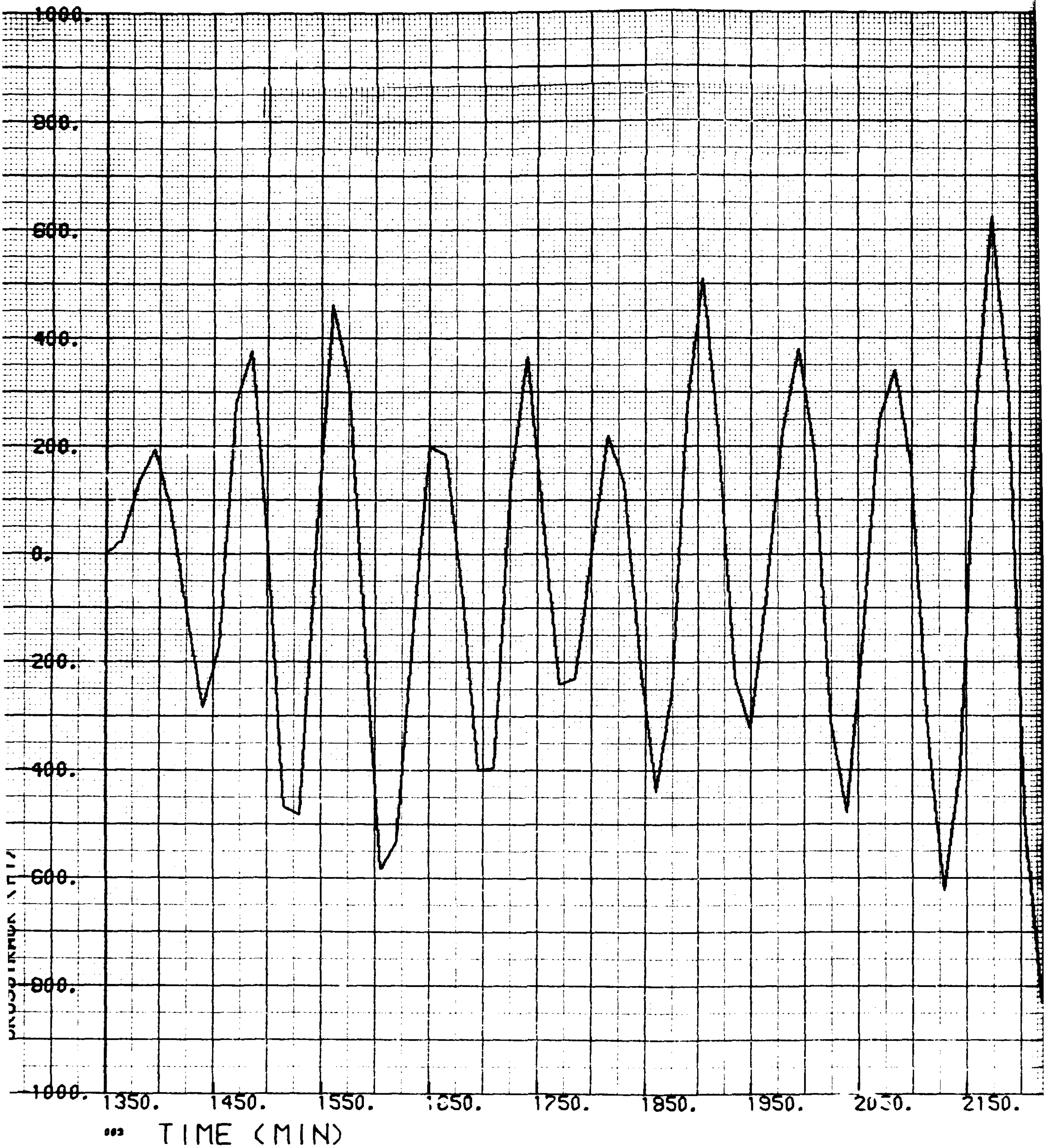

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TIME (MIN)

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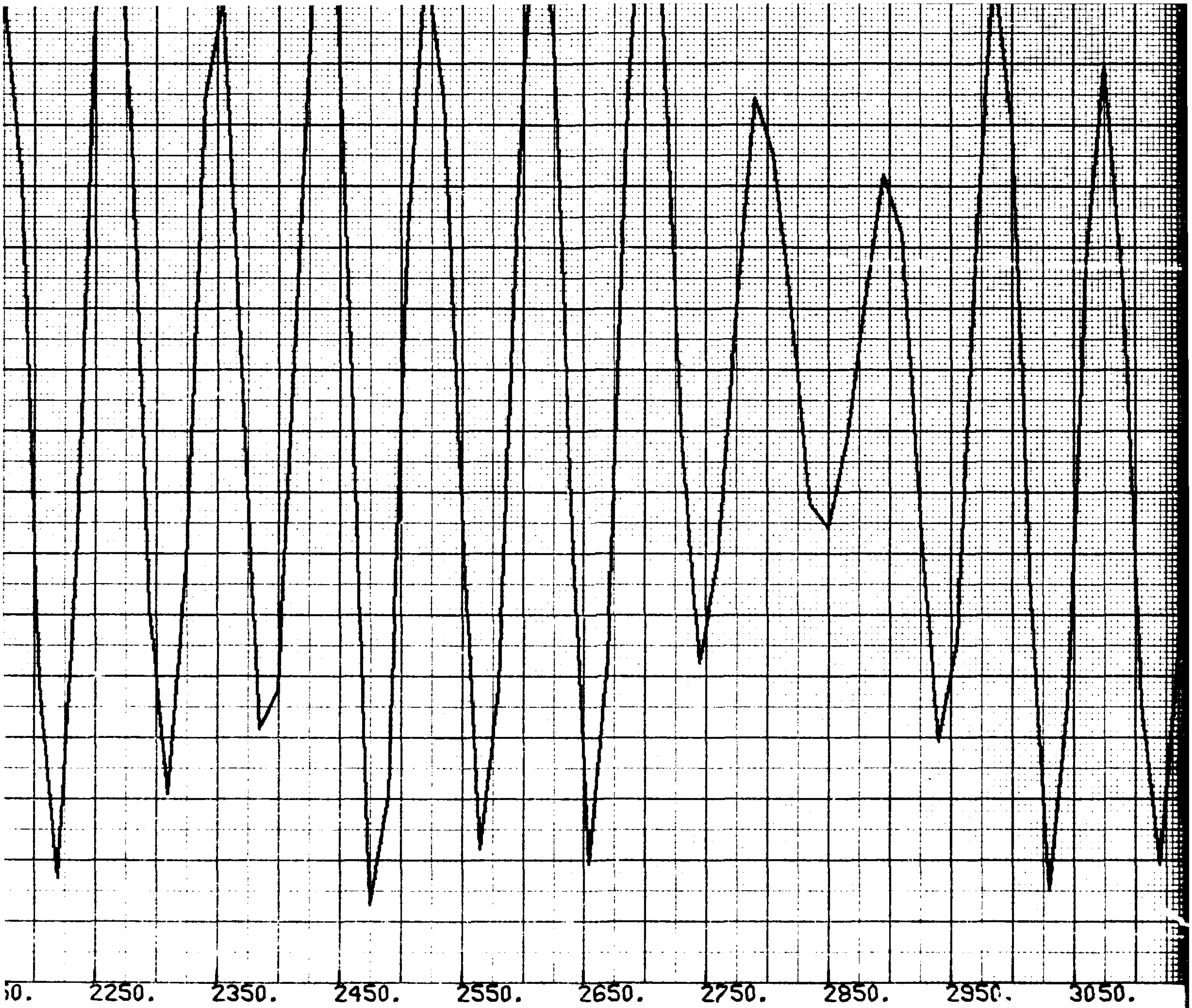

Figure VII-ic. Crosstrack Difference Between "Model" Ephemeris and "Real World" Ephemeris

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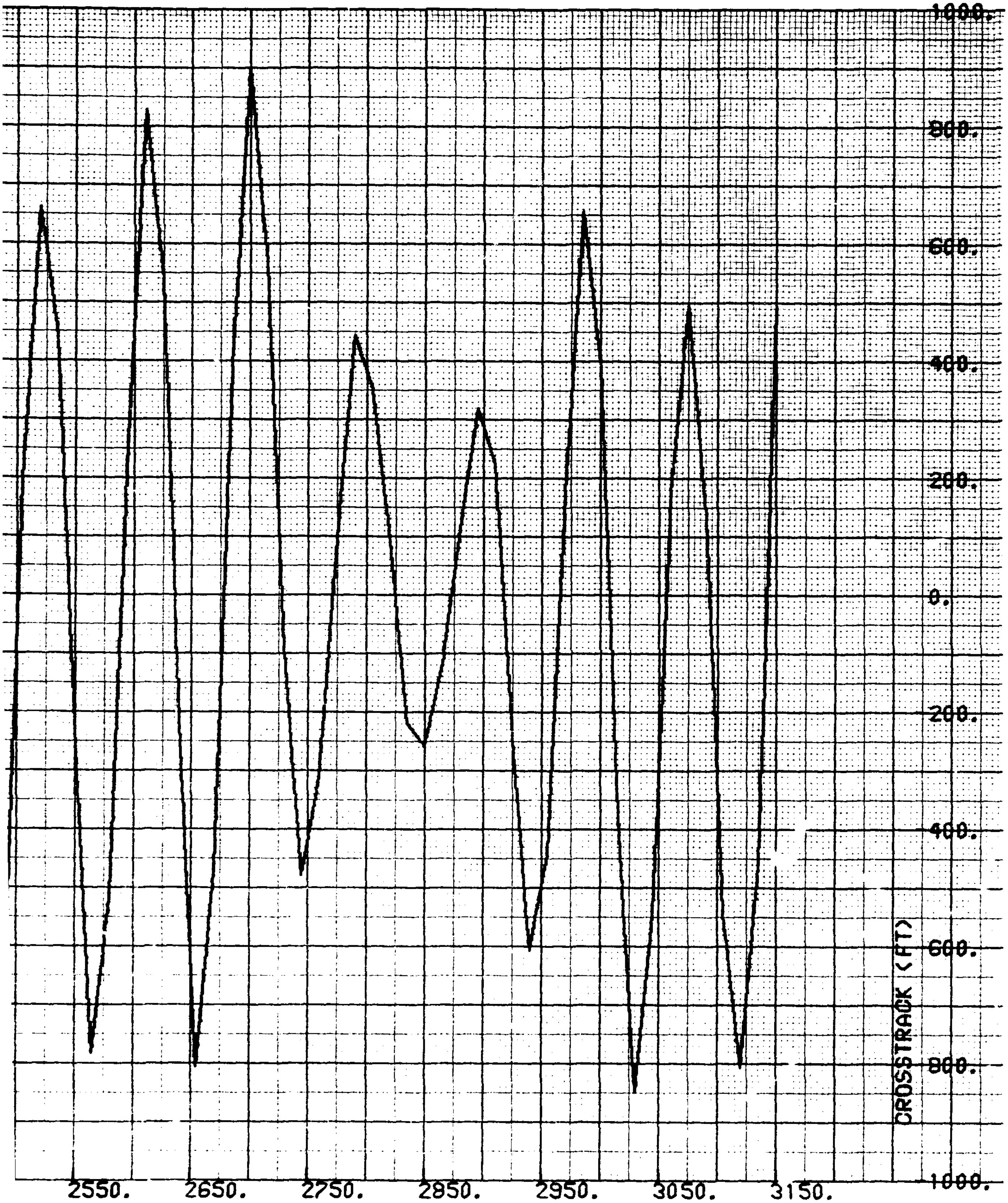


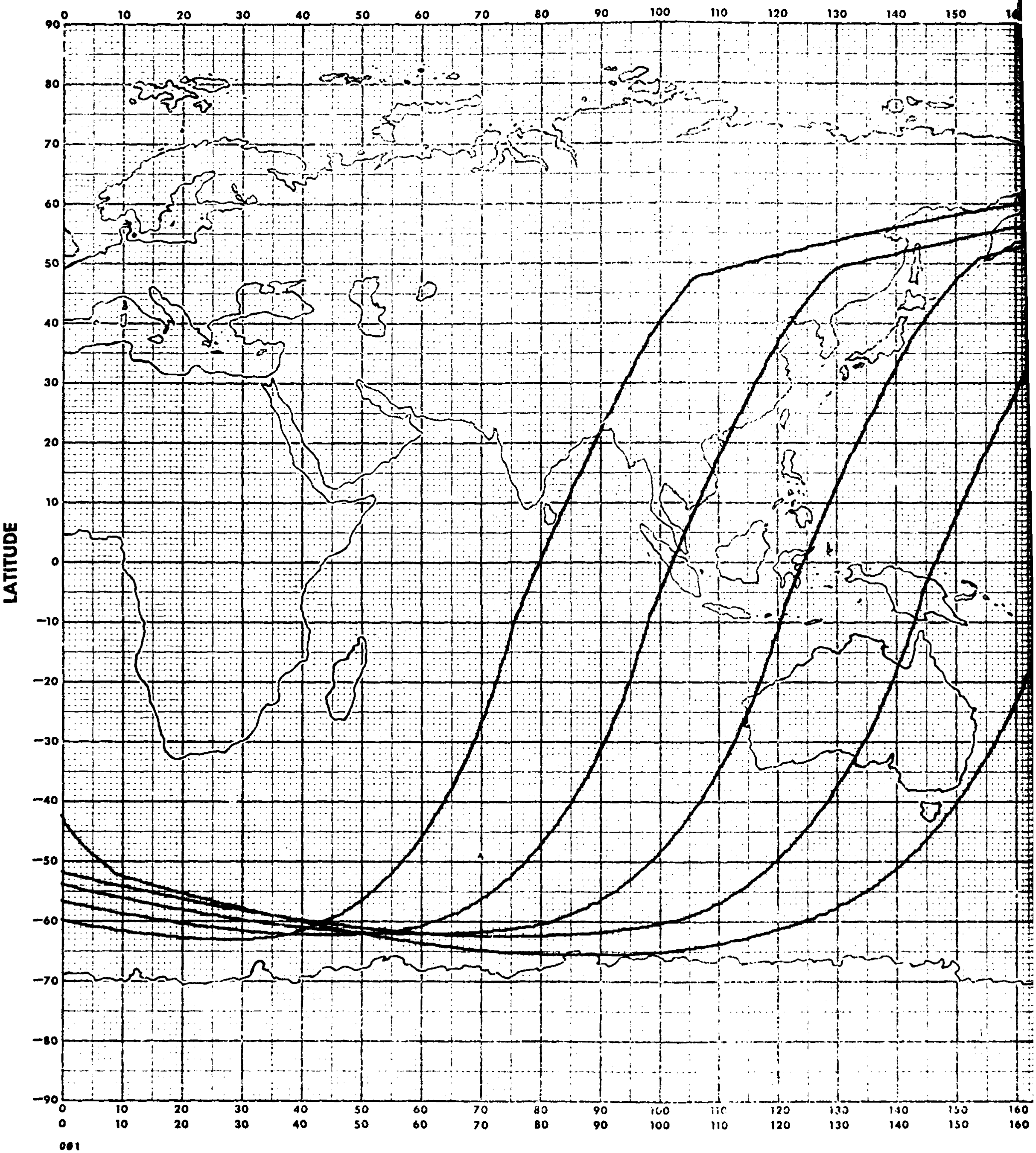
Figure VII-ic. Crosstrack Difference Between "Model" Ephemeris and "Real World" Ephemeris

Table VII-1. Selected Perigees from "Model" and "Real World" Ephemerides

Perigee	"Model"		"Real World"	
1	LAT	45.17868651°	LAT	45.16178965°
	LONG	193.33637181°	LONG	193.32125882°
	ALT	81.36217 n mi	ALT	81.36947 n mi
5	LAT	45.67476127°	LAT	45.72686973°
	LONG	104.69701390°	LONG	104.74014037°
	ALT	81.36473 n mi	ALT	81.46199 n mi
10	LAT	46.38336256°	LAT	46.44256510°
	LONG	354.06792672°	LONG	354.11780809°
	ALT	81.16635 n mi	ALT	81.44194 n mi
15	LAT	46.83655544°	LAT	46.78575569°
	LONG	243.30253604°	LONG	243.25405421°
	ALT	80.79841 n mi	ALT	81.16392 n mi
20	LAT	47.48427983°	LAT	47.43200754°
	LONG	132.81690727°	LONG	132.76370666°
	ALT	80.54562 n mi	ALT	81.12460 n mi

APPENDIX A

GROUND TRACE OF THE "MODEL" EPHEMERIS


LATITUDE
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
90 80 70 60 50 40 30 20 10 0 −10 −20 −30 −40 −50 −60 −70 −80 −90
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
001

A

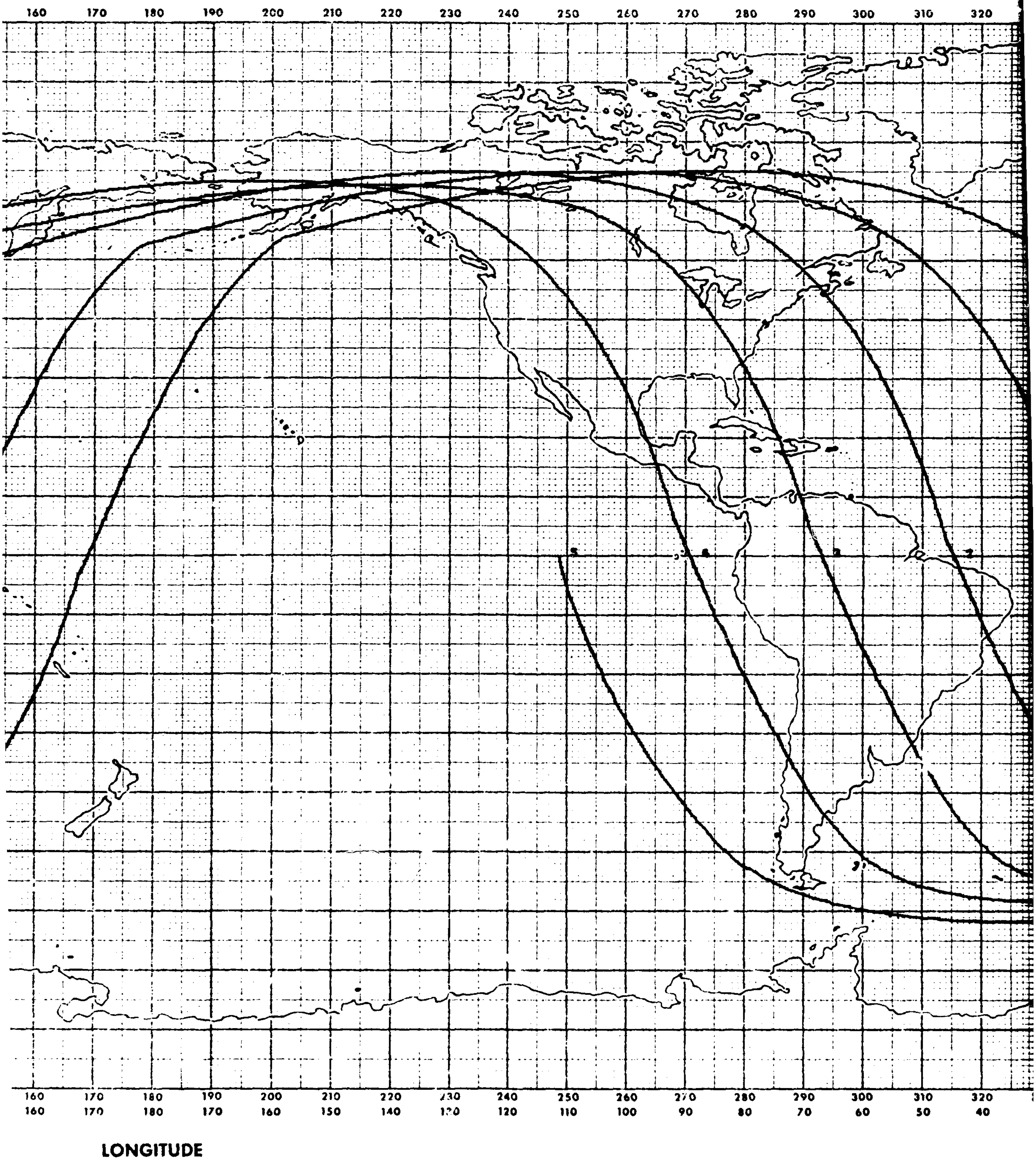


Figure A-1. Ground Trace, Revs 1 through 5

B

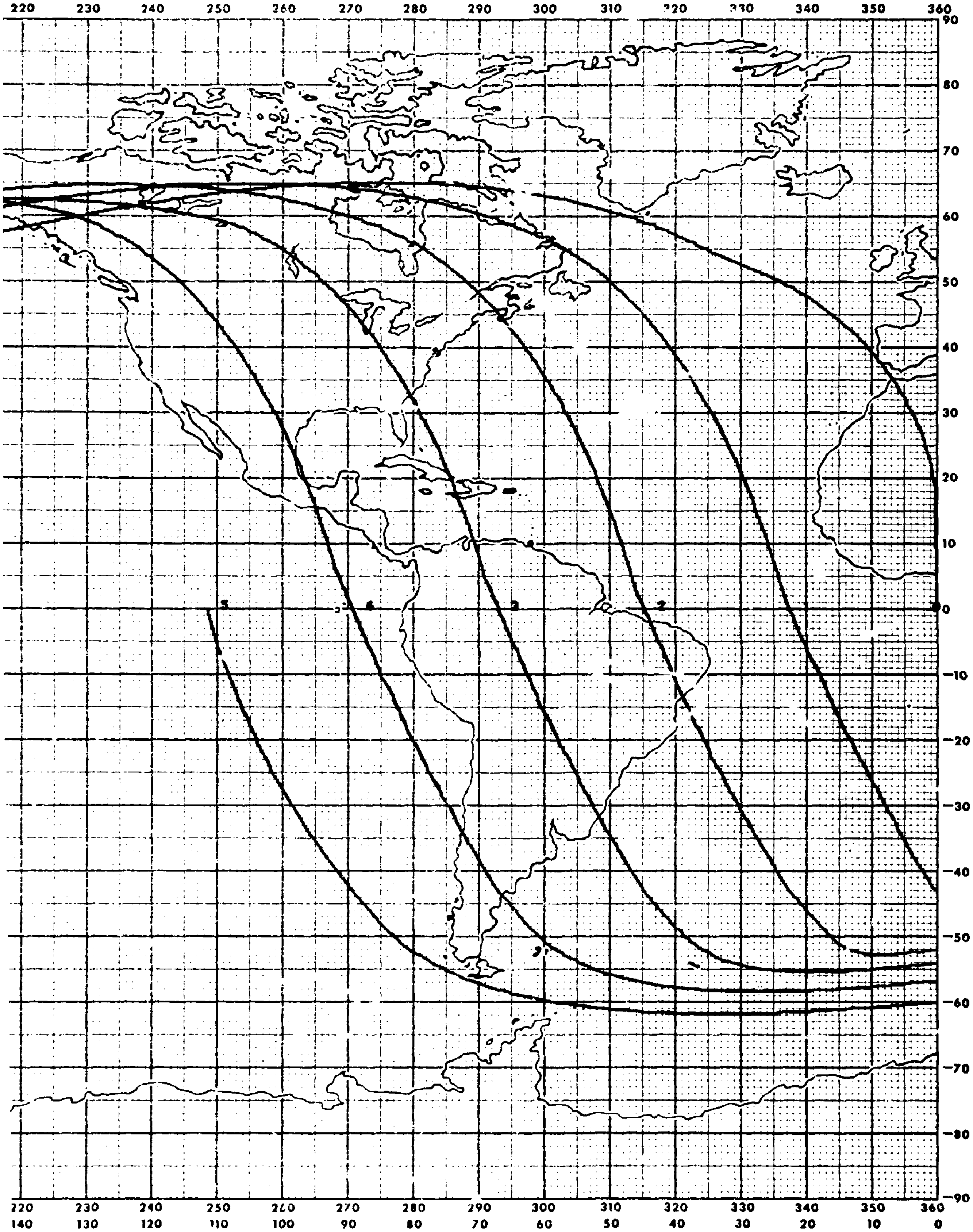
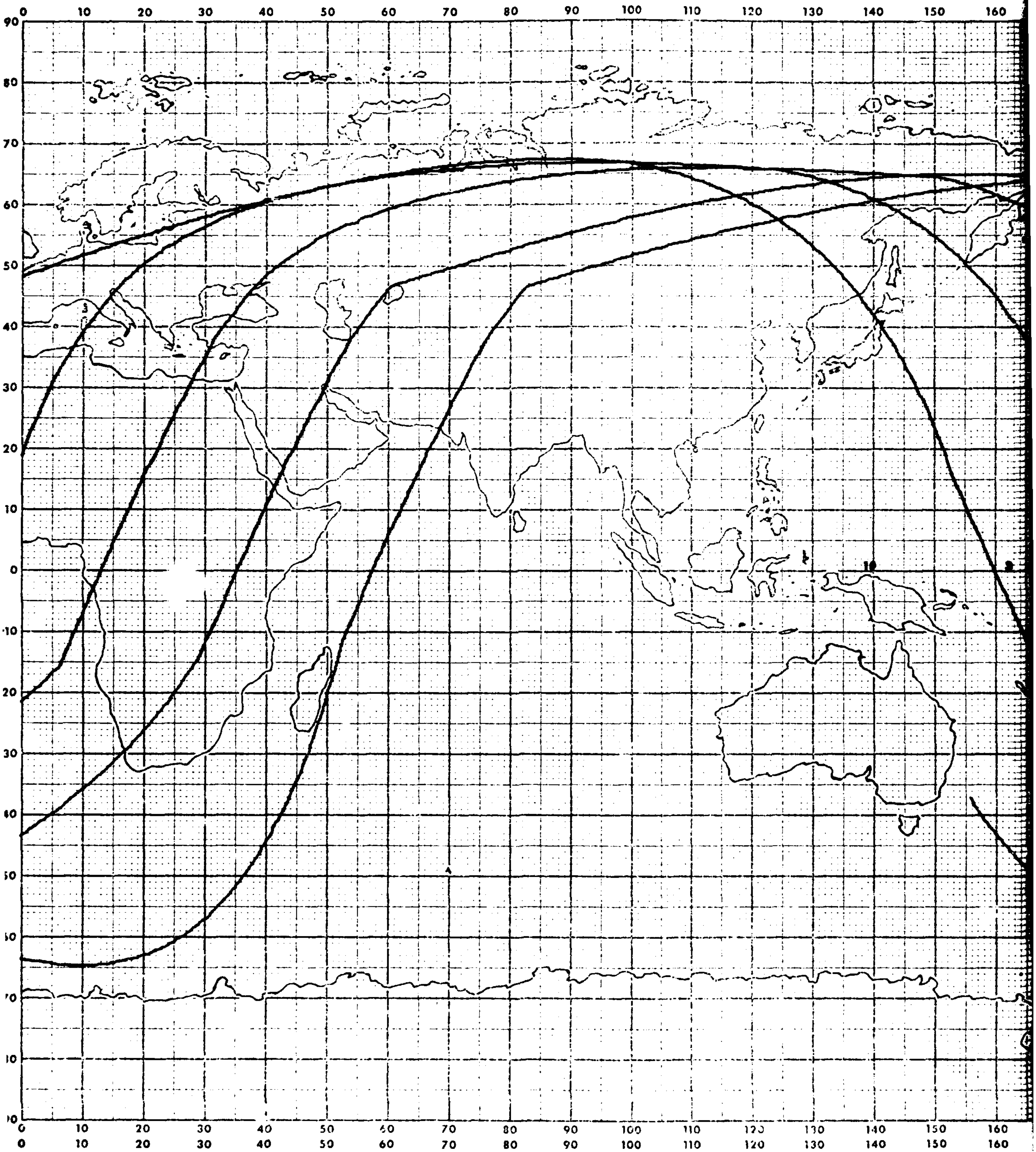
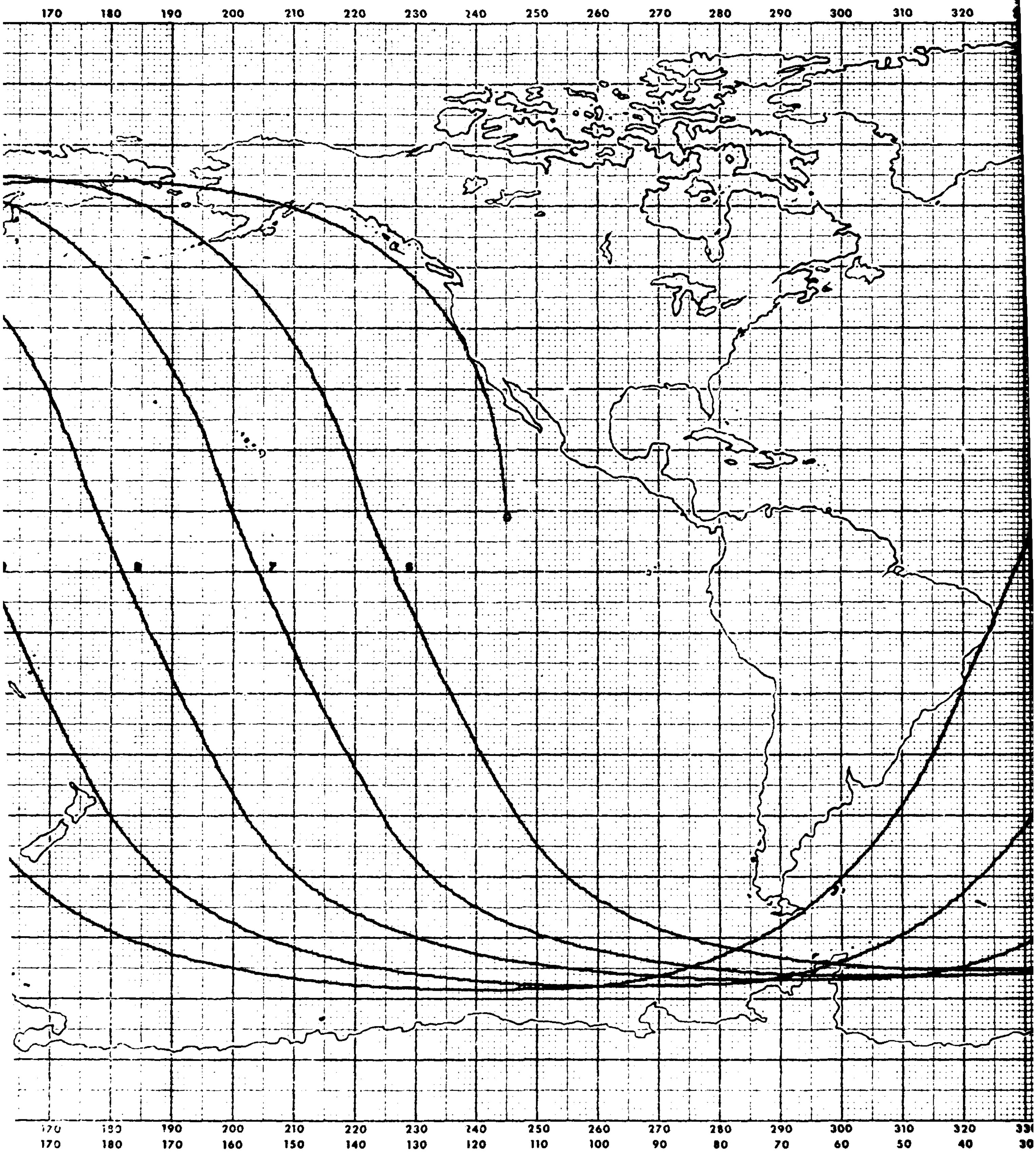


Figure A-1. Ground Trace, Revs 1 through 5


0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90
10
9

A



LONGITUDE

Figure A-2. Ground Trace, Revs 6 through 10

6

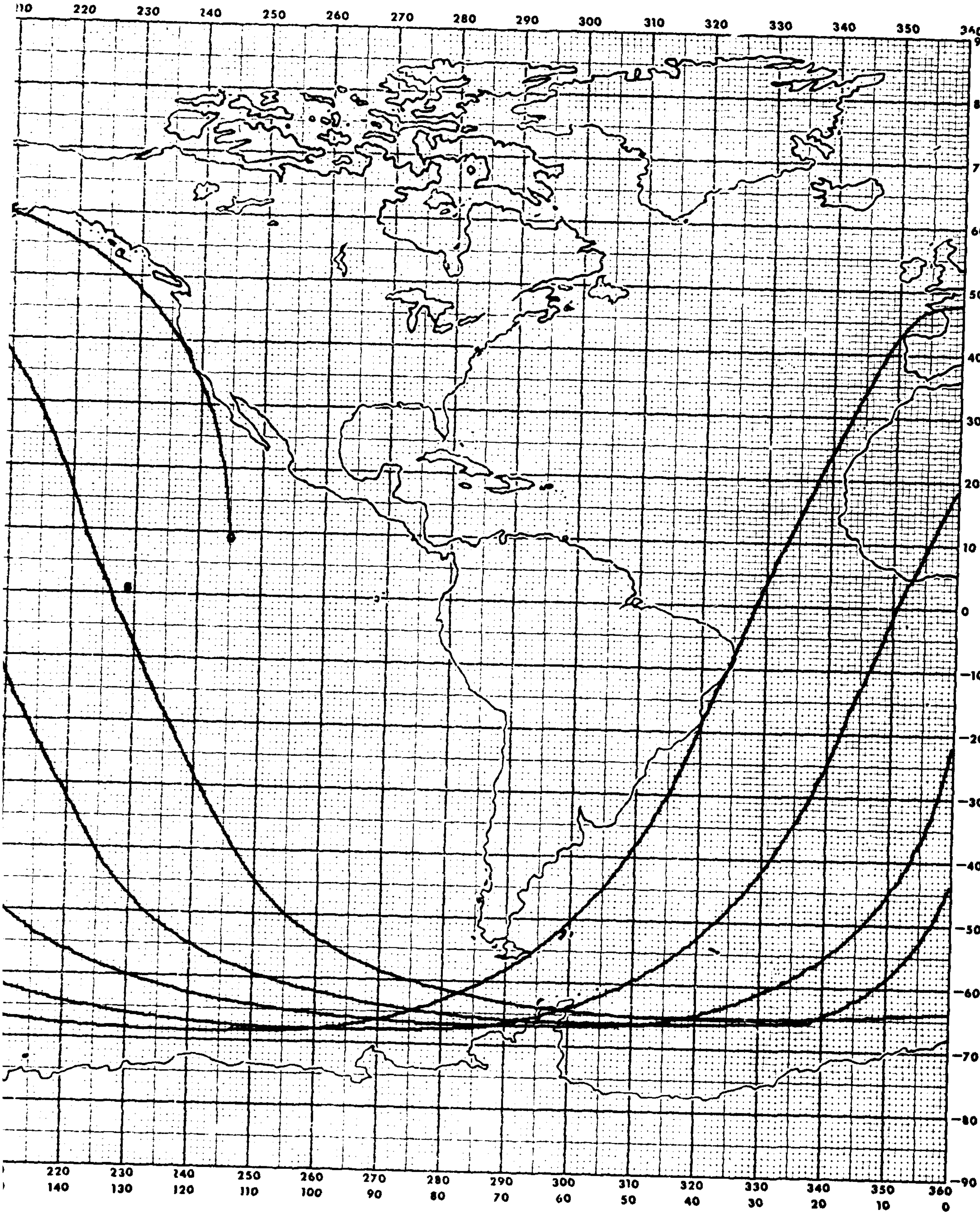
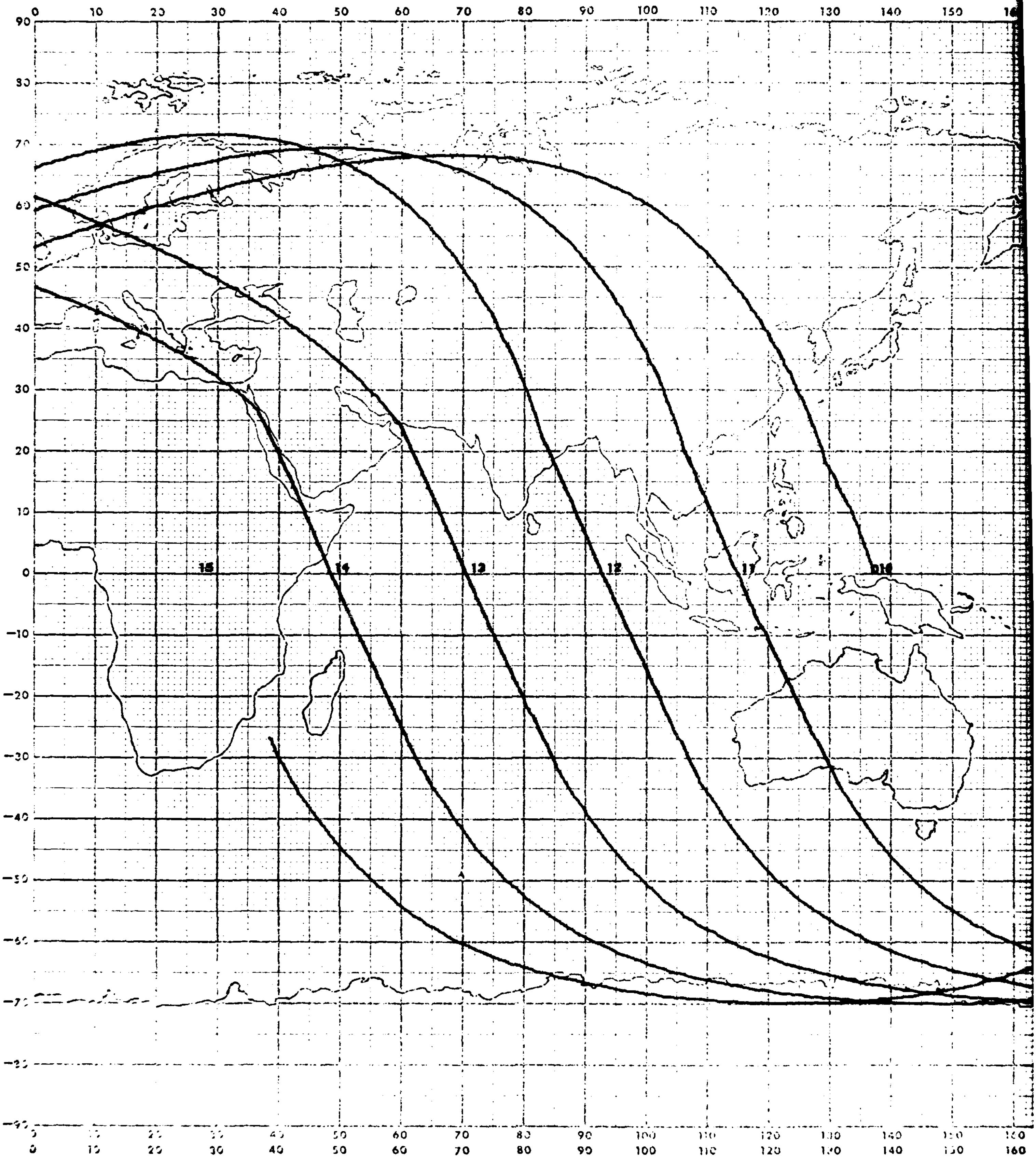


Figure A-2. Ground Trace, Revs 6 through 10

C


0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
90 80 70 60 50 40 30 20 10 0 −10 −20 −30 −40 −50 −60 −70 −80 −90
15
14
13
12
11
010

002

A

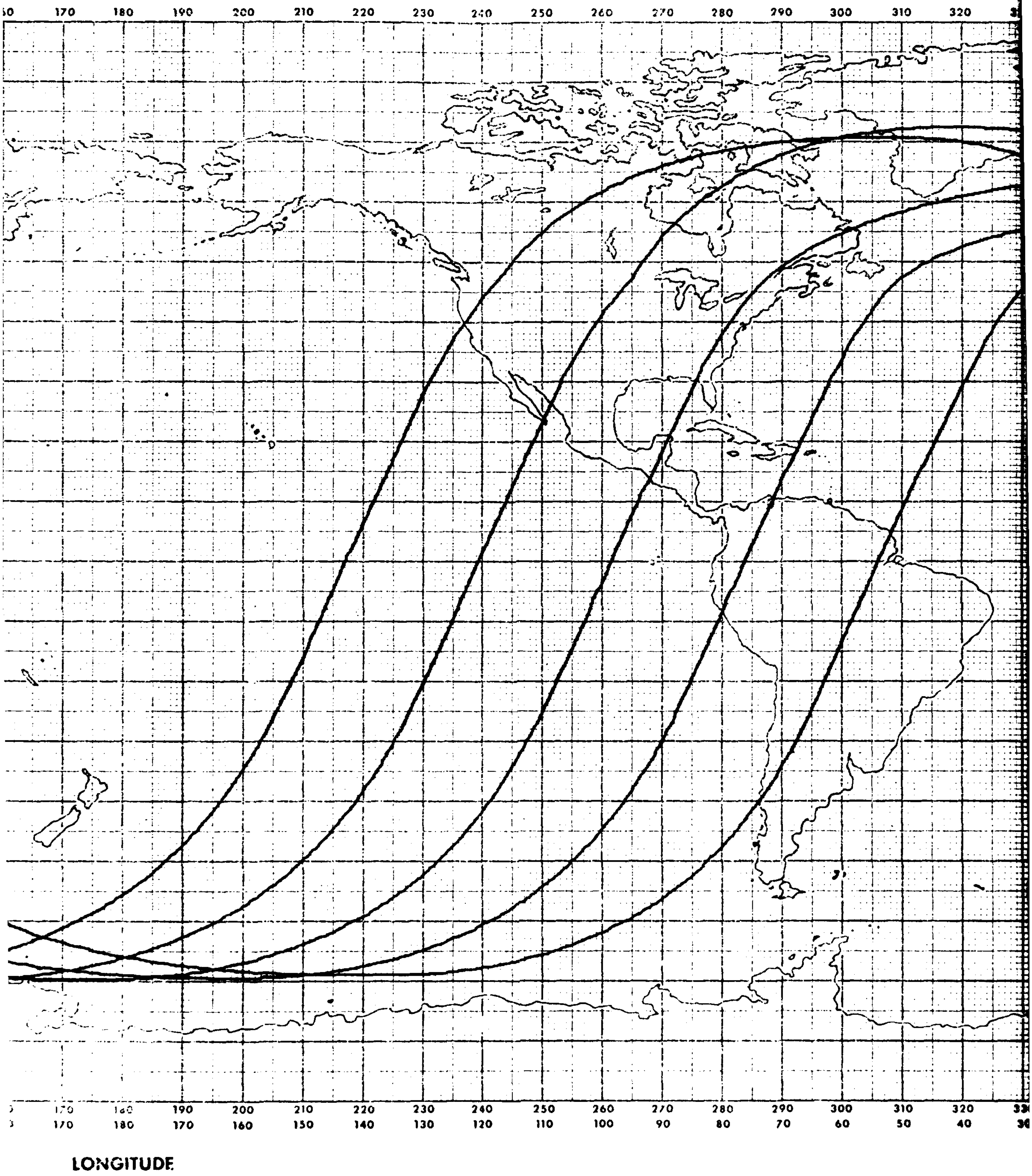


Figure A-3. Ground Trace, Revs 11 through 15

B

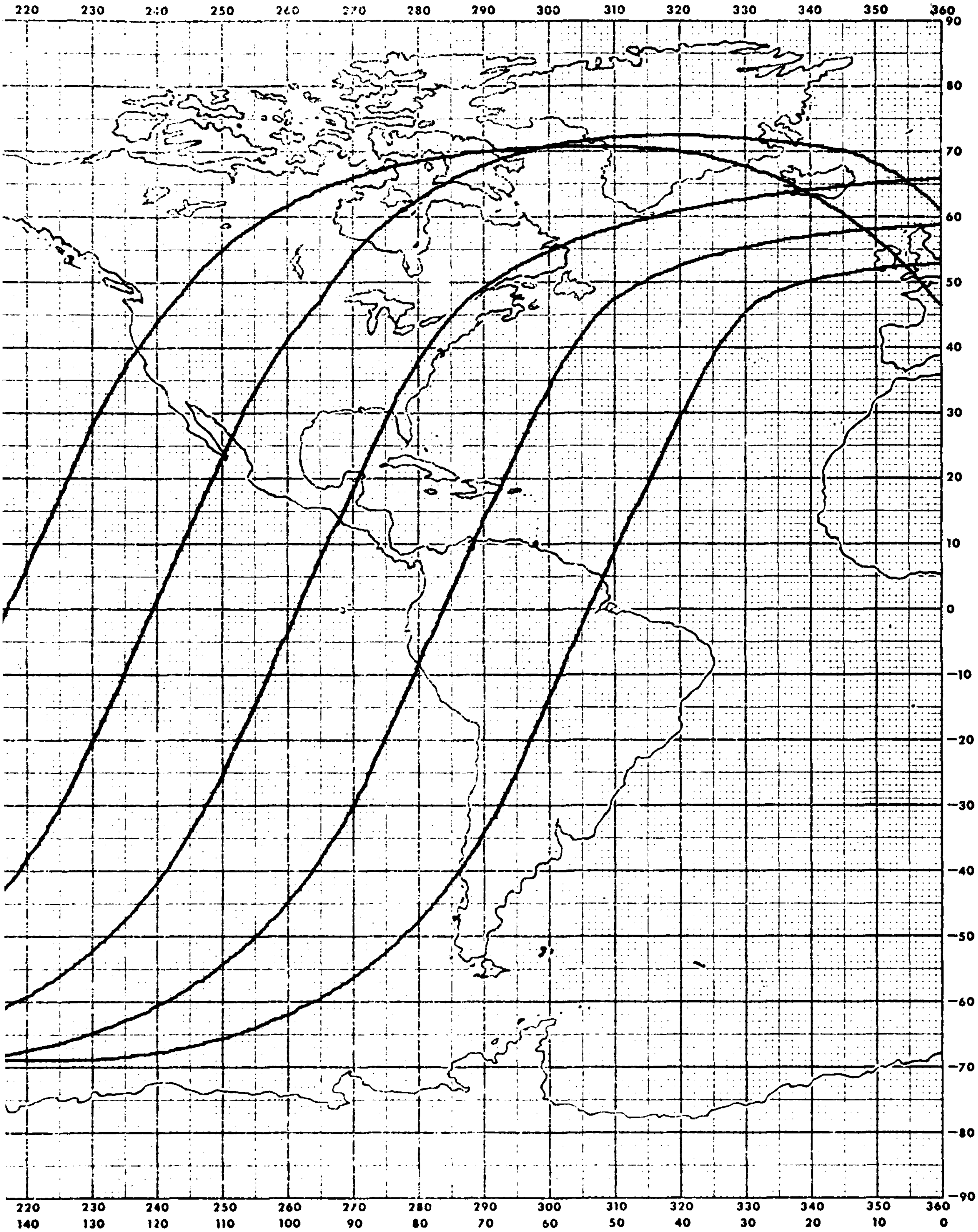
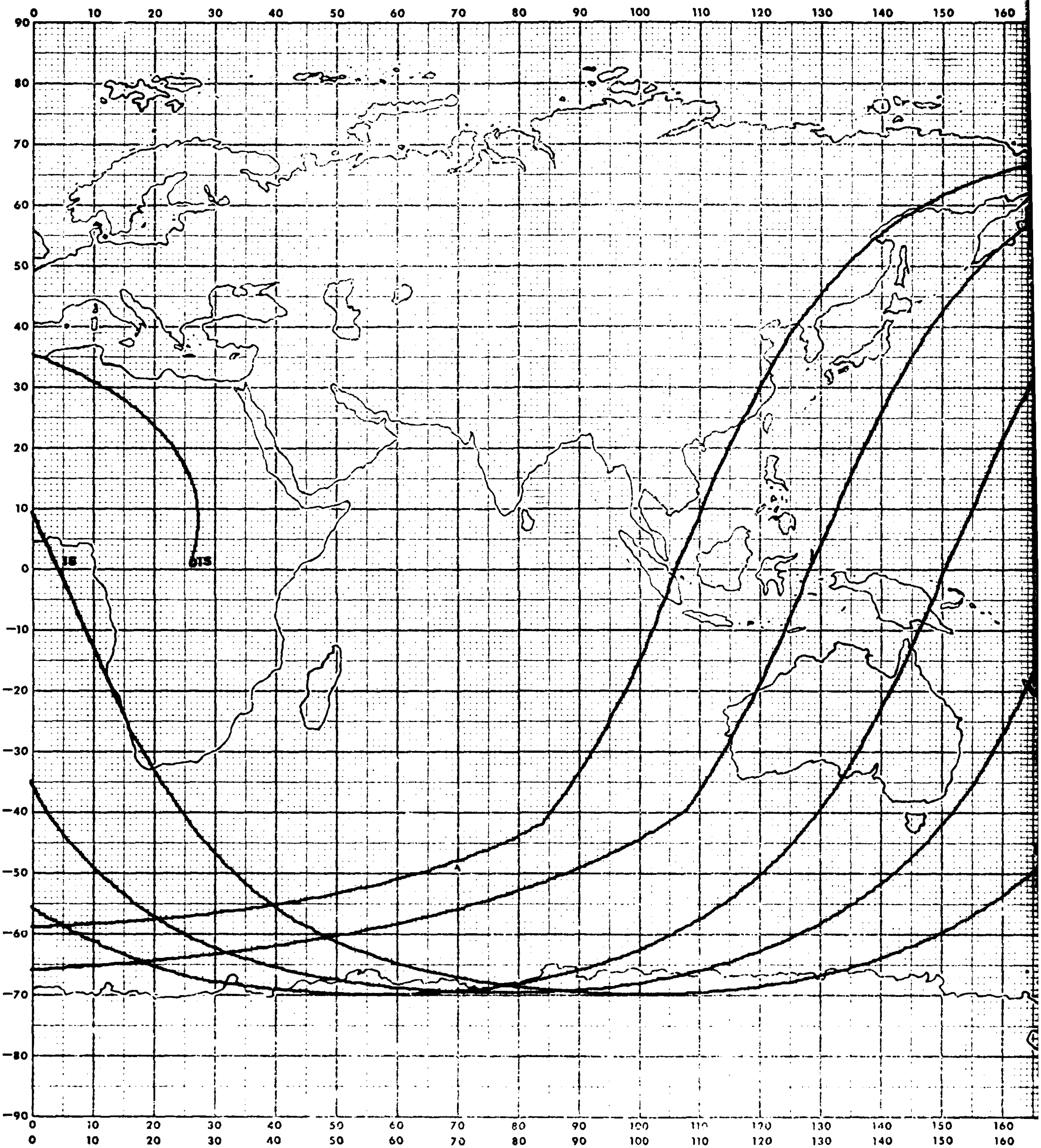


Figure A-3. Ground Trace, Revs 11 through 15

C



0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160
90 80 70 60 50 40 30 20 10 0 −10 −20 −30 −40 −50 −60 −70 −80 −90

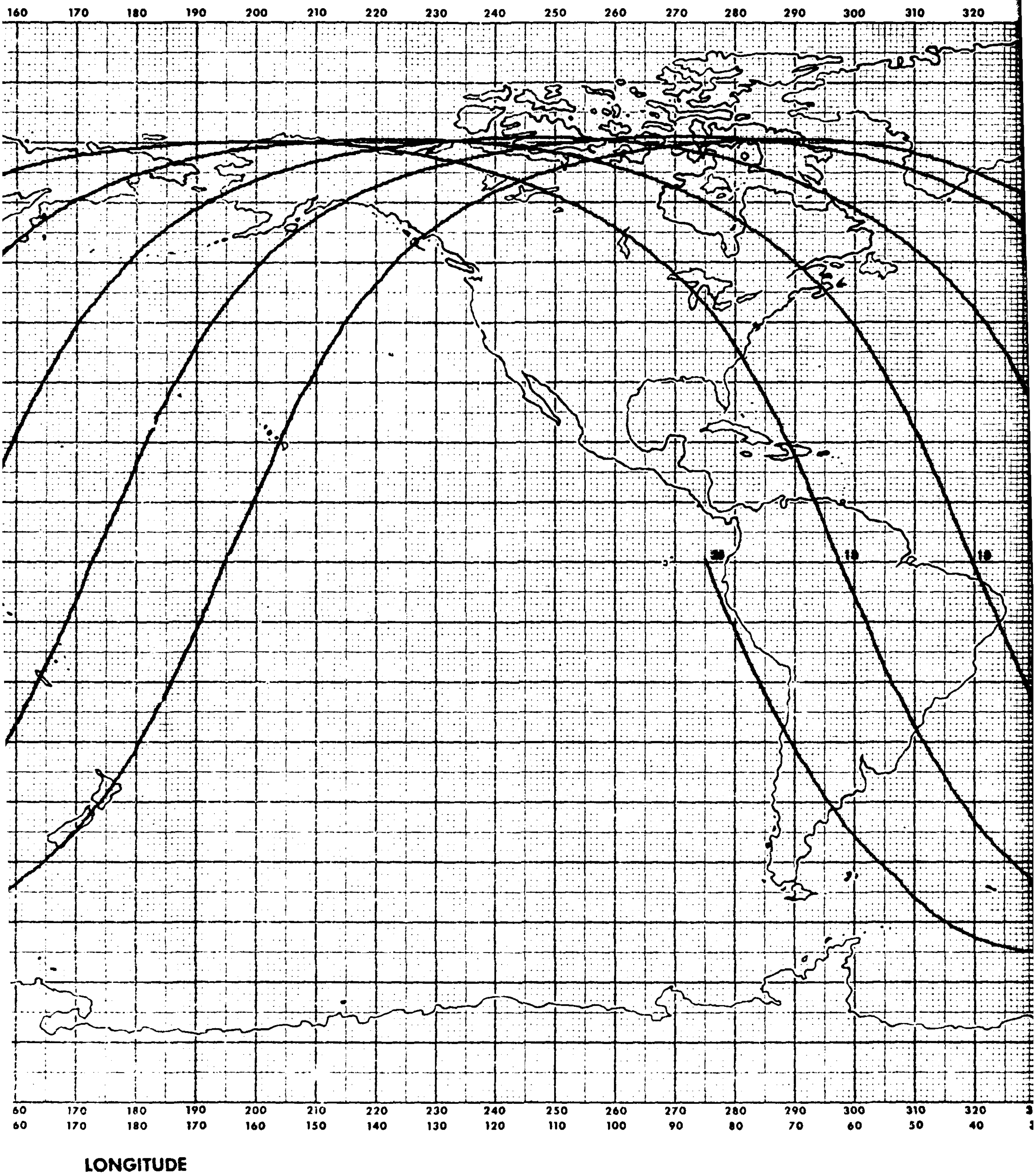


Figure A-4. Ground Trace, Revs 16 through 20

B

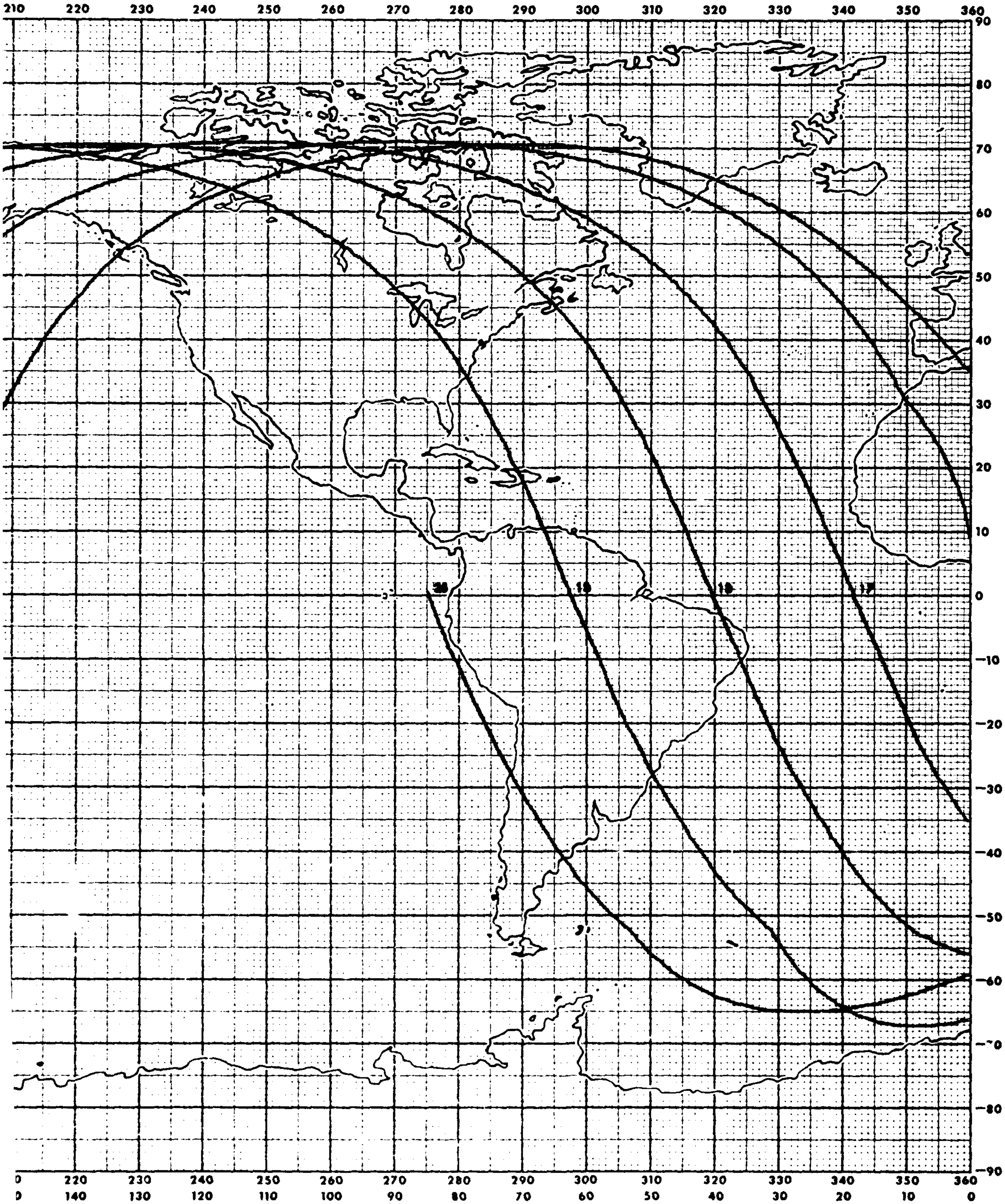


Figure A-4. Ground Trace, Revs 16 through 20

APPENDIX B

TIME HISTORY OF "REAL WORLD" EPHEMERIS; REVS 0 THROUGH 2

DATE,...	ME,MM,ST,DT	X,Y,Z,R	DX,DY,DZ,V	LAT,...	ALPHA,...	REV,...	REMARKS
MO/DAY/YR	MIN FROM EPOCH	X (FT)	DX (FT/SEC)	LATITUDE (DEG)	ALPHA (DEG)	REV COUNT	.
HR/MIN	MIN FROM MIDNIGHT	Y (FT)	DY (FT/SEC)	LONGITUDE(DEG)	DELTA (DEG)	PERIOD	.
SEC	SEC FROM MIDNIGHT	Z (FT)	DZ (FT/SEC)	ALTITUDE (NM)	BETA (DEG)	PER-DECAY	.
	S E SIZE(MIN)	R (FT)	V (FT/SEC)	S-VEH-LAT(DEG)	AZIMUTH(DEG)	NOD-REG	.

```
* * * * * * * * * * * * * * * * * * * * * * * * *
*                                               *
*        SPECIAL OUTPUT OPTIONS REQUESTED       *
*                                               *
* C  APOGEE-PERIGEE                             *
* D  MIN AND MAX HEIGHT ABOVE THE OBLATE EARTH  *
* K  KEPLERIAN ELEMENTS                         *
* L  VARIATIONAL EQUATIONS                      *
*                                               *
*                                               *
* * * * * * * * * * * * * * * * * * * * * * * * *
```

* * *   ECI TRAJECTORY   * * *

```
***  CASE    1
***

***  EPOCH PRINT

DATE,...    ME,MM,ST,DT        X,Y,Z,R              DX,DY,DZ,V           LAT,...         ALPHA,...       REV,...
 2/29/80        0.00000   -1.59387495E+07    5.16441283E+03       .00000000    136.39075374      .37886
 22/30       1350.00000    1.51831715E+07    5.00674669E+03    360.00000000       .00000000     0.00000
 0.00000    81000.00000    3.84199432E-15    2.36312409E+04      178.95205      90.72980142     0.00000
                 .16657    2.20130059E+07    2.51498815E+04       .00000000    339.99999959     0.00000
  A  =  2.17765010E+07     MEAN ANOM  =    2.30274791E+02      APOGEE  =    3.64393989E+03
  E  =  1.67381622E-02     ECCENTRIC  =    2.29545052E+02      HEIGHT  =    2.05817130E+02
  I  =  1.10000000E+02     TRUE ANOM  =    2.28819214E+02      PERIGEE =    3.52396238E+03
  O  =  1.36330754E+02     KEPL PER   =    8.96941070E+01      HEIGHT  =    8.58396196E+01
  U  =  1.31180786E+02     ANOM PER   =    8.95638881E+01      O-DOT   =   -2.96605943E+00
 TAU =  1.23262637E+03     NODL PER   =    8.95919216E+01      U-DOT   =    1.79995863E+00

***  REQUESTED PRINTS

DATE,...    ME,MM,ST,DT        X,Y,Z,R              DX,DY,DZ,V           LAT,...         ALPHA,...       REV,...
 2/29/80        0.00000   -1.59387495E+07    5.16441283E+03       .00000000    136.39075374     0.00000
 22/30       1350.00000    1.51831715E+07    5.00674669E+03    360.00000000       .00000000     0.00000
 0.00000    81000.00000    3.84199432E-15    2.36312409E+04      178.95205      90.72980142     0.00000
                 .16657    2.20130059E+07    2.51498815E+04       .00000000    339.99999959     0.00000

POSITION AND VELOCITY RELATIVE TO SUN
   DISTANCE MAG,X,Y,Z      4.8635421938E+11    -4.5847551193E+11    1.4890507074E+11    6.4559364676E+10
   VELOCITY MAG,X,Y,Z      8.4677354521E+04    -2.8024622038E+04   -7.8816167744E+04   -1.3152499522E+04

POSITION AND VELOCITY RELATIVE TO MOON
   DISTANCE MAG,X,Y,Z      1.3054905340E+09     1.1361107374E+09   -5.8673251967E+08   -2.6325489201E+08
   VELOCITY MAG,X,Y,Z      2.7080059638E+04     7.7966792304E+03    8.6410262251E+03    2.4451463939E+04
RHO  =  5.28370424E-14
  A  =  2.17765010E+07     MEAN ANOM  =    2.30274791E+02      APOGEE  =    3.64393989E+03
  E  =  1.67381622E-02     ECCENTRIC  =    2.29545052E+02      HEIGHT  =    2.05817130E+02
  I  =  1.10000000E+02     TRUE ANOM  =    2.28819214E+02      PERIGEE =    3.52396238E+03
  O  =  1.36330754E+02     KEPL PER   =    8.96941070E+01      HEIGHT  =    8.58396196E+01
  U  =  1.31180786E+02     ANOM PER   =    8.95638881E+01      O-DOT   =   -2.96605943E+00
 TAU =  1.23262637E+03     NODL PER   =    8.95919216E+01      U-DOT   =    1.79995863E+00
```

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DATE,....   ME,MM,ST,DT        X,Y,Z,R            DX,DY,DZ,V          LAT,....       ALPHA,....      REV,....
 2/23/80        15.00000   -3.45158689E+05    1.91040501E+04    54.52853318   105.88113937      .16627
 20/45        1365.00000    1.21323373E+07   -1.22964391E+04   325.73011882    54.34645179     0.00000
 0.00000     81300.00000    1.75840955E+07    1.17083668E+04    125.27529      90.95667154     0.00000
                  .16667    2.15404525E+07    2.55591893E+04    54.52214324   324.03079754     0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z        4.8634503617E+11    -4.5849378747E+11    1.4882567691E+11    5.4543842348E+10
    VELOCITY MAG,X,Y,Z        1.0143537613E+05    -1.5069249783E+04   -3.7124771743E+04   -2.5077122877E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z        1.3144154403E+09     1.1500640666E+03   -5.8741090496E+08   -2.4493133070E+08
    VELOCITY MAG,X,Y,Z        2.6077698734E+04     2.0730070729E+04   -3.6588783781E+03    1.2530525934E+04
RHO  =    3.7300768?E-13
 A   =    2.1733372?E+07     MEAN ANOM   =   2.85393924E+02     APOGEE   =   3.63861410E+03
 E   =    1.7241?348E-02     ECCENTRIC   =   2.84443205E+02     HEIGHT   =   1.99566786E+02
 I   =    1.1007?437E+02     TRUE ANOM   =   2.83494477E+02     PERIGEE  =   3.51527367E+03
 O   =    1.3640855?E+02     KEPL PER    =   8.94311842E+01     HEIGHT   =   7.62263580E+01
 U   =    1.3637734?E+02     ANOM PER    =   8.95643493E+01     O-DOT    =  -2.98948347E+00
 TAU =    1.?3411039E+03     NODL PER    =   8.95923336E+01     U-DOT    =   1.50737022E+00

DATE,....   ME,MM,ST,DT        X,Y,Z,R            DX,DY,DZ,V          LAT,....       ALPHA,....      REV,....
 2/23/80        30.00000    1.24271645E+07    1.27191925E+04    53.31384393   345.53028160      .33773
 23/ 0        1380.00000   -3.20687692E+05   -1.85173539E+04   201.51993+55    53.12928216     0.00000
 0.00000     82800.00000    1.71119432E+07   -1.27992565E+04     83.82862      90.16292021     0.00000
                  .16667    2.13903412E+07    2.58551972E+04    53.30945584   214.78922008     0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z        4.8632659943E+11    -4.5850865616E+11    1.4873398970E+11    5.4519261564E+10
    VELOCITY MAG,X,Y,Z        1.1661854226E+05    -2.1436371415E+04   -1.0335110202E+05   -4.9597634181E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z        1.3353472170E+09     1.1674035600E+09   -5.0037484332E+08   -2.4466402054E+08
    VELOCITY MAG,X,Y,Z        2.4517307839E+04     1.4338960159E+04   -1.5876525467E+04   -1.1975155565E+04
RHO  =    3.74915571E-12
 A   =    2.17337035E+07     MEAN ANOM   =   3.43963950E+02     APOGEE   =   3.63437575E+03
 E   =    1.50662033E-02     ECCENTRIC   =   3.49807051E+02     HEIGHT   =   1.96108844E+02
 I   =    1.1001?624E+02     TRUE ANOM   =   3.43642842E+02     PERIGEE  =   3.51944104E+03
 O   =    1.35465513E+02     KEPL PER    =   8.94233533E+01     HEIGHT   =   8.11741263E+01
 U   =    1.71333339E+02     ANOM PER    =   8.95597834E+01     O-DOT    =  -2.98927826E+00
 TAU =    1.23305177E+03     NODL PER    =   8.95875593E+01     U-DOT    =   1.80750546E+00
```

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DATE,...   ME,MM,ST,DT      X,Y,Z,R          DX,DY,DZ,V        LAT,...      ALPHA,...      REV,...
 2/23/80      32.30650   1.40090598E+07   1.00889914E+04   45.15178365  337.81077404    .36443   BETA =90
 23/ 2      1392.30650  -5.71391950E+06  -1.76293523E+04  133.32125982   44.96936118   0.00000
18.39588   82338.39588   1.51133558E+07  -1.60161228E+04   91.36347    90.00000001    0.00000
               .16667    2.13849513E+07   2.58665780E+04   45.15734313  208.93278082   0.00000

POSITION AND VELOCITY RELATIVE TO SUN
   DISTANCE MAG,X,Y,Z     4.8632426685E+11   -4.5851180108E+11    1.4871974196E+11    5.4503171677E+10
   VELOCITY MAG,X,Y,Z     1.1775541075E+05   -2.4064898963E+04   -1.0246393356E+05   -5.2804921358E+04

POSITION AND VELOCITY RELATIVE TO MOON
   DISTANCE MAG,X,Y,Z     1.3382313600E+09    1.1692095635E+09   -5.0251636123E+08   -2.4654858353E+08
   VELOCITY MAG,X,Y,Z     2.4341606537E+04    1.1706996815E+04   -1.4988023199E+04   -1.5192812092E+04
RHO  =   4.68329969E-12      RHOSP   =   2.98263130E-12     PH+.554 =   1.60491274E+02
SHT  =   1.95900158E+01
  A  =   2.17423530E+07     MEAN ANOM   :   3.59993999E+02     APOGEE   =   3.63734934E+03
  E  =   1.64651827E-02     ECCENTRIC   :   3.59993999E+02     HEIGHT   =   1.99218131E+02
  I  =   1.10015130E+02     TRUE ANOM   =   3.59993993E+02     PERIGEE  =   3.51951034E+03
  O  =   1.36472033E+02     KEPL PER    =   8.94869180E+01     HEIGHT   =   8.13791281E+01
  U  =   1.31222333E+02     ANOM PER        8.95574340E+01     O-DOT    =  -2.98422584E+00
 TAU =   1.29281368E+03     NODL PER        8.95853312E+01     U-DOT    =   1.80594915E+00

DATE,...   ME,MM,ST,DT      X,Y,Z,R          DX,DY,DZ,V        LAT,...      ALPHA,...      REV,...
 2/23/80      34.63891   1.52175979E+07   7.14357504E+03   36.50601275  332.00623446    .39137   HMIN-MAX
 23/ 4      1394.63891  -8.08921632E+06  -1.62385065E+04  186.93204435   36.32216159   0.00000
38.33473   83078.33473   1.25698964E+07  -1.88237624E+04   80.50178    89.83736047    0.00000
               .16667    2.13901141E+07   2.58661369E+04   36.50180213  205.13251959   0.00000

POSITION AND VELOCITY RELATIVE TO SUN
   DISTANCE MAG,X,Y,Z     4.8632226984E+11   -4.5851537169E+11    1.4870549495E+11    6.4435580010E+10
   VELOCITY MAG,X,Y,Z     1.1848259279E+05   -2.7036812986E+04   -1.0107402889E+05   -5.5512925928E+04

POSITION AND VELOCITY RELATIVE TO MOON
   DISTANCE MAG,X,Y,Z     1.3408188615E+09    1.1706445730E+09   -5.0452198967E+08   -2.4887681134E+08
   VELOCITY MAG,X,Y,Z     2.4200055474E+04    8.7614073699E+03   -1.3598770253E+04   -1.9000229559E+04
RHO  =   5.09521431E-12
  A  =   2.17528625E+07     MEAN ANOM   =   9.49643013E+00     APOGEE   .   3.64061996E+03
  E  =   1.69156977E-02     ECCENTRIC   =   9.65904689E+00     HEIGHT   :   2.02510905E+02
  I  =   1.10010431E+02     TRUE ANOM   =   9.82304253E+00     PERIGEE  =   3.51950151E+03
  O  =   1.35476936E+02     KEPL PER    =   8.95491015E+01     HEIGHT   =   8.13924548E+01
  U  =   1.31099740E+02     ANOM PER    =   8.9555 [illegible]92E+01     O-DOT    =  -2.97888066E+00
 TAU =   1.38227573E+03     NODL PER    =   8.95834489E+01     U-DOT    =   1.80428816E+00
```

```
DATE,...   ME,MM,ST,DT       X,Y,Z,R            DX,DY,DZ,V          LAT,...       ALPHA,...     REV,...
 2/29/80        44.07646   1.55959287E+07   -5.82983951E+03    -.00000000   316.48277818      .0000   OSC NODE
 23/14        1394.07646  -1.48089004E+07   -5.60375329E+03  169.04274246    -.00000000     0.00000
 4.58738     83544.58738  -1.70590147E-04   -2.41873896E+04      95.59335   89.28871587     0.00000
                  .16667   2.15065210E+07    2.57415307E+04    -.00000000  199.39917247     0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z       4.8631896012E+11   -4.5833432822E+11    1.4865073612E+11    5.4462077735E+10
    VELOCITY MAG,X,Y,Z       1.1695145327E+05   -3.9959697172E+04   -3.1442581075E+04   -5.0978029529E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z       1.3466217140E+09    1.1719378135E+09   -5.0974500373E+08   -2.6108011406E+08
    VELOCITY MAG,X,Y,Z       2.4068291041E+04   -4.2159465191E+03   -3.9598707059E+03   -2.3362958985E+04
RHO  =   1.63123530E-12
  A  =   2.17761329E+07      MEAN ANOM  =    4.43562340E+01      APOGEE   =    3.64674042E+03
  E  =   1.75333758E-02      ECCENTRIC  =    4.50674453E+01      HEIGHT   =    2.09079206E+02
  I  =   1.09333173E+02      TRUE ANOM  =    4.57831339E+01      PERIGEE  =    3.52106038E+03
  O  =   1.36492779E+02      KEP. PER   =    8.96922025E+01      HEIGHT   =    8.23991604E+01
  U  =   1.34216866E+02      ANOM PER   =    8.95525701E+01      O-DOT    =   -2.96625059E+00
 TAU =   1.38302532E+03      NODL PER   =    8.95805085E+01      U-DOT    =    1.80034723E+00

DATE,...   ME,MM,ST,DT       X,Y,Z,R            DX,DY,DZ,V          LAT,...       ALPHA,...     REV,...
 2/29/80        45.00000   1.52391203E+07   -7.03961032E+03   -3.59135139   315.18262380      .51046
 23/15        1395.00000  -1.51422825E+07   -5.42870717E+03  167.51107105    -3.56737123     0.00000
 0.00000     83700.00000  -1.33931400E+06   -2.41347405E+04      98.63430    89.24969242     0.00000
                  .16667   2.15247130E+07    2.57199989E+04   -3.59067930   200.03981267     0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z       4.8631909349E+11   -4.5953657658E+11    1.4864570148E+11    5.4458699751E+10
    VELOCITY MAG,X,Y,Z       1.1542968408E+05   -4.1171437475E+04   -3.0267868143E+04   -5.0925525044E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z       1.3467252210E+09    1.1716705267E+09   -5.0993197812E+08   -2.6237374062E+08
    VELOCITY MAG,X,Y,Z       2.4094978824E+04   -5.4261029778E+03   -2.7845246221E+03   -2.3310222172E+04
RHO  =   1.35772235E-12
  A  =   2.17759447E+07      MEAN ANOM  =    4.78666895E+01      APOGEE   =    3.64640388E+03
  E  =   1.74516597E-02      ECCENTRIC  =    4.86169257E+01      HEIGHT   =    2.07705579E+02
  I  =   1.09939323E+02      TRUE ANOM  =    4.93715617E+01      PERIGEE  =    3.52131528E+03
  O  =   1.36432795E+02      KEPL PER   =    8.96905701E+01      HEIGHT   =    8.26169840E+01
  U  =   1.34425065E+02      ANOM PER   =    8.95531131E+01      O-DOT    =   -2.96637306E+00
 TAU =   1.38307446E+03      NODL PER   =    8.95803503E+01      U-DOT    =    1.80037218E+00

DATE,...   ME,MM,ST,DT       X,Y,Z,R            DX,DY,DZ,V          LAT,...       ALPHA,...     REV,...
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2/29/80       60.00000   2.21025035E+06  -1.90619502E+04  -58.09123073  280.96109083     .57877
23/30       1410.00000  -1.14121226E+07   1.27647444E+04  129.52927027  -57.91829080    0.00000
0.00000    84600.00000  -1.85436914E+07  -1.05934934E+04     166.32363   89.10501902    0.00000
                .16657   2.18858457E+07   2.52688530E+04  -58.08326799  220.13765457    0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z       4.8633148229E+11   -4.5858032296E+11    1.4857307397E+11    6.4408382612E+10
    VELOCITY MAG,X,Y,Z       1.0133856455E+05   -5.3183939591E+04   -7.2079826698E+04   -4.7385623479E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z       1.3372208944E+09    1.1600910299E+09   -5.0382062473E+08   -2.7883539201E+08
    VELOCITY MAG,X,Y,Z       2.5250748777E+04   -1.7454610305E+04    1.5412067561E+04   -9.7675517081E+03
RHO  =   8.12393757E-14
  A  =   2.17283538E+07      MEAN ANOM  =   1.13998955E+02      APOGEE  =   3.63760334E+03
  E  =   1.72191535E-02      ECCENTRIC  =   1.14893876E+02      HEIGHT  =   1.99928924E+02
  I  =   1.10021888E+02      TRUE ANOM  =   1.15785614E+02      PERIGEE =   3.51445090E+03
  O  =   1.36504544E+02      KEPL PER   =   8.93968049E+01      HEIGHT  =   7.67764894E+01
  J  =   1.28603312E+02      ANOM PER   =   8.95488299E+01      O-DOT   =  -2.99236157E+00
TAJ  =   1.38163127E+03      NODL PER   =   8.95767125E+01      U-DOT   =   1.80864841E+00

DATE,...   ME,MM,ST,DT        X,Y,Z,R         DX,DY,DZ,V         LAT,...      ALPHA,...      REV,...
2/29/80       75.00000  -1.31473643E+07  -1.20218463E+04  -52.03922398  164.19652107     .84199
23/45       1425.00000   3.72119131E+06   1.78028025E+04    9.00443330  -51.85242330    0.00000
0.00000    85530.00000  -1.73953688E+07   1.27905867E+04     203.86383   89.81419697    0.00000
                .16657   2.21208973E+07   2.50012738E+04  -52.02878118  326.34372010    0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z       4.8635139155E+11   -4.5852638232E+11    1.4851184473E+11    6.4376415063E+10
    VELOCITY MAG,X,Y,Z       8.4848552223E+04   -4.5127197689E+04   -5.7047175996E+04   -2.4004887828E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z       1.3158794598E+09    1.1461771444E+09   -5.8630320684E+08   -2.7594405429E+08
    VELOCITY MAG,X,Y,Z       2.6690502159E+04   -1.0420881710E+04    2.0453352758E+04    1.3617947380E+04
RHO  =   2.47448146E-14
  A  =   2.17356432E+07      MEAN ANOM  =   1.59447695E+02      APOGEE  =   3.64168362E+03
  E  =   1.80186559E-02      ECCENTRIC  =   1.69633468E+02      HEIGHT  =   2.03173787E+02
  I  =   1.10018841E+02      TRUE ANOM  =   1.69817625E+02      PERIGEE =   3.51276998E+03
  O  =   1.36559428E+02      KEPL PER   =   8.94417946E+01      HEIGHT  =   7.42601493E+01
  U  =   1.33358332E+02      ANOM PER   =   8.95510452E+01      O-DOT   =  -2.98858286E+00
TAJ  =   1.38290082E+03      NODL PER   =   8.95783362E+01      U-DOT   =   1.80737498E+00

DATE,...   ME,MM,ST,DT        X,Y,Z,R         DX,DY,DZ,V         LAT,...      ALPHA,...      REV,...
2/29/80       75.53001  -1.35209659E+07  -1.14720565E+04  -50.31387130  162.41668597     .84771   HMIN-MAX
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 23/45        1425.53001   4.28476955E+06   1.76377482E+04     7.09173262  -50.12462705     0.00000
31.80067     85531.80067  -1.69782728E+07   1.35013081E+04     203.90930    89.34894975     0.00000
                 .16657    2.21232347E+07   2.49995712E+04   -50.30329592  327.72851112     0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z       4.8635260520E+11   -4.5862784103E+11    1.4850971002E+11    6.4375663037E+10
    VELOCITY MAG,X,Y,Z       8.4483002924E+04   -4.5576815799E+04   -5.7212421423E+04   -2.3294249313E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z       1.3162167974E+09    1.1458544523E+09   -5.8565533539E+08   -2.7643965520E+08
    VELOCITY MAG,X,Y,Z       2.6727789367E+04   -9.8713131215E+03    2.0288412126E+04    1.4328718773E+04
RHO  =   2.46789331E-14
  A  =   2.17374659E+07     MEAN ANOM   =    1.71400623E+02     APOGEE   =   3.64171266E+03
  E  =   1.79413659E-02     ECCENTRIC   =    1.71551650E+02     HEIGHT   =   2.03171632E+02
  I  =   1.10017929E+02     TRUE ANOM   =    1.71701360E+02     PERIGEE  =   3.51334122E+03
  O  =   1.36550355E+02     KEPL PER    =    8.94531516E+01     HEIGHT   =   7.48001929E+01
  U  =   1.33534243E+02     ANOM PER    =    8.95503903E+01     O-DOT    =  -2.98755828E+00
 TAU =   1.38294026E+03     NODL PER    =    8.95789835E+01     U-DOT    =   1.80705764E+00

DATE,...    ME,MM,ST,DT        X,Y,Z,R          DX,DY,DZ,V           LAT,...       ALPHA,...      REV,...
 2/29/80        77.79338   -1.49113381E+07   -8.96412739E+03   -42.63057347   155.36292629     .87213    BETA =90
 23/47        1427.79338    6.61936421E+06    1.66753113E+04      .17058077   -42.49982236     0.00000
47.50300     85657.60300   -1.49489402E+07    1.63255733E+04     203.11721     89.99999995     0.00000
                 .16657    2.21277257E+07    2.49993841E+04   -42.67987498   332.34183482     0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z       4.8635508532E+11   -4.5853386285E+11    1.4850052171E+11    6.4372695423E+10
    VELOCITY MAG,X,Y,Z       8.3196050324E+04   -4.3056360926E+04   -5.8175073975E+04   -2.0470237778E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z       1.3135489722E+09    1.1446813559E+09   -5.8296073238E+08   -2.7435734136E+08
    VELOCITY MAG,X,Y,Z       2.6870137412E+04   -7.3643315044E+03    1.9327060949E+04    1.7153297675E+04
RHO  =   2.51441692E-14
  A  =   2.17455537E+07     MEAN ANOM   =    1.79993997E+02     APOGEE   =   3.64175544E+03
  E  =   1.75638037E-02     ECCENTRIC   =    1.79993997E+02     HEIGHT   =   2.03126791E+02
  I  =   1.10013846E+02     TRUE ANOM   =    1.79999997E+02     PERIGEE  =   3.51593517E+03
  O  =   1.36556121E+02     KEPL PER    =    8.95036285E+01     HEIGHT   =   7.73665174E+01
  U  =   1.34028417E+02     ANOM PER    =    8.95507947E+01     O-DOT    =  -2.98295829E+00
 TAU =   1.38304157E+03     NODL PER    =    8.95785972E+01     U-DOT    =   1.80562692E+00

DATE,...    ME,MM,ST,DT        X,Y,Z,R          DX,DY,DZ,V           LAT,...       ALPHA,...      REV,...
 2/29/80        89.58105   -1.59847365E+07    6.14523072E+03    -.00000000   136.57494797     1.00000   ASC NODE
 23/59        1433.58105    1.51293069E+07    5.02755263E+03   337.72761571     -.00000000     0.00000
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34.95323     45374.95323  -4.34333501E-04   2.36341645E+04     178.34217   90.72838080    0.00000
                  .16667   2.20093002E+07   2.51523113E+04     -.00000000  340.00045711    0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z        4.8636164935E+11   -4.5865905075E+11   1.4844901842E+11    5.4361619428E+10
    VELOCITY MAG,X,Y,Z        8.4663699378E+04   -2.7943848580E+04  -7.8827679804E+04   -1.3133587897E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z        1.3058544333E+09    1.1447377124E+09  -5.7257479755E+08   -2.5882324803E+08
    VELOCITY MAG,X,Y,Z        2.7097011136E+04    7.7410889770E+03   9.6812267524E+03    2.4452900421E+04
RHO  =    5.33313394E-14
  A  =    2.17743825E+07      MEAN ANOM   =    2.30405954E+02     APOGEE   =    3.64335094E+03
  E  =    1.66727404E-02      ECCENTRIC   =    2.29677636E+02     HEIGHT   =    2.05251841E+02
  I  =    1.09939542E+02      TRUE ANOM   =    2.28953184E+02     PERIGEE  =    3.52385400E+03
  O  =    1.36574348E+02      KEPL PER    =    8.96810185E+01     HEIGHT   =    8.57548939E+01
  U  =    1.31046816E+02      ANOM PER    =    8.95507656E+01     O-DOT    =   -2.96699152E+00
 TAU =    1.38213372E+03      NODL PER    =    8.95787021E+01     U-DOT    =    1.80067509E+00

DATE,...    ME,MM,ST,DT        X,Y,Z,R          DX,DY,DZ,V         LAT,...       ALPHA,...     REV,...
 3/ 1/80        30.00000  -1.58236573E+07   6.67417011E+03    1.55752436   136.01171655    1.00457
  0/ 0        1440.00000   1.52744760E+07   5.52136512E+03  337.05936197     1.54710253    0.00000
0.00000          0.00000   5.94003582E+05   2.36242498E+04   177.00323     90.74848579    0.00000
                  .16667   2.20011497E+07   2.51623096E+04    1.55701143   339.99283230    0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z        4.8536165435E+11   -4.5865974659E+11   1.4844703960E+11    5.4361299454E+10
    VELOCITY MAG,X,Y,Z        8.4364025125E+04   -2.7414441144E+04  -7.9333418283E+04   -1.3173558067E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z        1.3058152387E+09    1.1449389300E+09  -5.7236291985E+08   -2.5820541159E+08
    VELOCITY MAG,X,Y,Z        2.7077055125E+04    8.2688533226E+03   9.1757287582E+03    2.4453025135E+04
RHO  =    5.63304504E-14
  A  =    2.17743480E+07      MEAN ANOM   =    2.32173574E+02     APOGEE   =    3.6434676 E+03
  E  =    1.67063154E-02      ECCENTRIC   =    2.31431150E+02     HEIGHT   =    2.05383863E+02
  I  =    1.09939563E+02      TRUE ANOM   =    2.30686562E+02     PERIGEE  =    3.52372594E+03
  O  =    1.36574948E+02      KEPL PER    =    8.96808054E+01     HEIGHT   =    8.56421563E+01
  U  =    1.30959852E+02      ANOM PER    =    8.95505933E+01     O-DOT    =   -2.96701759E+00
 TAU =    1.38216097E+03      NODL PER    =    8.95785298E+01     U-DOT    =    1.80068429E+00

DATE,...    ME,MM,ST,DT        X,Y,Z,R          DX,DY,DZ,V         LAT,...       ALPHA,...     REV,...
 3/ 1/80       135.00000  -3.00373561E+06   1.92577436E+04   55.33201791   104.27690665    1.17103
  0/15        1455.00000   1.18042397E+07  -1.25543569E+04  301.55428528    55.72313314    0.00000
0.00000        900.00000   1.79713377E+07   1.10870796E+04   123.39857     90.94149209    0.00000
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                 .16657  2.16274728E+07  2.55720933E+04  55.89583216  322.56507473   0.00000

POSITION AND VELOCITY RELATIVE TO SUN
   DISTANCE MAG,X,Y,Z      4.8535203167E+11   -4.5857759886E+11    1.4836718909E+11    6.4345446698E+10
   VELOCITY MAG,X,Y,Z      1.0193105939E+05   -1.4814127227E+04   -3.7515742327E+04   -2.5713090353E+04

POSITION AND VELOCITY RELATIVE TO MOON
   DISTANCE MAG,X,Y,Z      1.3153896967E+09    1.1591912121E+09   -5.7344326785E+08   -2.4018452598E+08
   VELOCITY MAG,X,Y,Z      2.6010431491E+04    2.0846137835E+04   -9.9979933074E+03    1.1917265349E+04
RHO  =   4.10873779E-13
 A   =   2.17300159E+07     MEAN ANOM  =  2.86965381E+02    APOGEE  =  3.63743924E+03
 E   =   1.70954329E-02     ECCENTRIC  =  2.85023942E+02    HEIGHT  =  1.98370523E+02
 I   =   1.10019635E+02     TRUE ANOM  =  2.85083228E+02    PERIGEE =  3.51516242E+03
 O   =   1.36593216E+02     KEPL PER   =  8.94070685E+01    HEIGHT  =  7.60937015E+01
 U   =   1.36437936E+02     ANOM PER   =  8.95502609E+01    O-DOT   = -2.99121184E+00
TAU  =   1.38373130E+03     NODL PER   =  8.95781505E+01    U-DOT   =  1.80870127E+00

DATE,...   ME,MM,ST,DT      X,Y,Z,R         DX,DY,DZ,V       LAT,...     ALPHA,...     REV,...
 3/ 1/80     120.00000   1.27557641E+07   1.23204922E+04   51.86077194  344.09333409   1.34258
 0/30       1470.00000  -3.63517938E+06  -1.83518723E+04  177.62044531   51.67368687   0.00000
0.00000     1500.00000   1.67788280E+07  -1.34167552E+04   83.23474     90.12927340   0.00000
                .16657   2.13881536E+07   2.58572052E+04   51.85635564  213.50256712   0.00000

POSITION AND VELOCITY RELATIVE TO SUN
   DISTANCE MAG,X,Y,Z      4.8633355507E+11   -4.5859249645E+11    1.4827537154E+11    6.4311232991E+10
   VELOCITY MAG,X,Y,Z      1.1682609973E+05   -2.1734637273E+04   -1.0321805723E+05   -5.0219256059E+04

POSITION AND VELOCITY RELATIVE TO MOON
   DISTANCE MAG,X,Y,Z      1.3352958852E+09    1.1753775308E+09   -5.8548992475E+08   -2.4052921652E+08
   VELOCITY MAG,X,Y,Z      2.4451953333E+04    1.3902590374E+04   -1.5691722510E+04   -1.2585153345E+04
RHO  =   3.94987133E-12
 A   =   2.17332953E+07     MEAN ANOM  =  3.52044144E+02    APOGEE  =  3.63421368E+03
 E   =   1.50402162E-02     ECCENTRIC  =  3.51914887E+02    HEIGHT  =  1.95014442E+02
 I   =   1.10017127E+02     TRUE ANOM  =  3.51784587E+02    PERIGEE =  3.51946709E+03
 O   =   1.36650742E+02     KEPL PER   =  8.94273027E+01    HEIGHT  =  8.12678558E+01
 U   =   1.31606319E+02     ANOM PER   =  8.95468529E+01    O-DOT   = -2.98906467E+00
TAU  =   1.38254900E+03     NODL PER   =  8.95747482E+01    U-DOT   =  1.80823470E+00

DATE,...   ME,MM,ST,DT      X,Y,Z,R         DX,DY,DZ,V       LAT,...     ALPHA,...     REV,...
 3/ 1/80     121.83512   1.39976228E+07   1.02035944E+04   45.33747505  338.13025735   1.36387   BETA =90
 0/31       1471.83512  -5.61842344E+05  -1.76195113E+04  171.19733361   45.14505290   0.00000
50.10718    1910.10718   1.51596717E+07  -1.59515660E+04   81.40345     89.99999996   0.00000
                .16657   2.13845427E+07   2.58653532E+04   45.33302599  209.02784920   0.00000
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POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z        4.8633171686E+11   -4.5869500419E+11    1.4826404388E+11    5.4305561599E+10
    VELOCITY MAG,X,Y,Z        1.1770851115E+05   -2.3849486818E+04   -1.0248645666E+05   -5.2754353163E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z        1.3385608454E+09    1.1777935519E+09   -5.8818023845E+08   -2.4205675637E+08
    VELOCITY MAG,X,Y,Z        2.4315975465E+04    1.1784921854E+04   -1.4959072670E+04   -1.5119802399E+04
RHO  =   4.67020469E-12       RHOSP      =   2.97423777E-12       PH+.5S4 =    1.60568355E+12
SHT  =   1.96183123E+01
  A  =   2.17403073E+07      MEAN ANOM   =   2.65266807E-06       APOGEE  =    3.63664449E+03
  E  =   1.63685117E-02      ECCENTRIC   =   2.69681085E-06       HEIGHT  =    1.98548691E+02
  I  =   1.10013589E+02      TRUE ANOM   =   2.74132089E-06       PERIGEE =    3.51950891E+03
  O  =   1.36655716E+02      KEPL PER    =   8.94736719E+01       HEIGHT  =    8.14131100E+01
  U  =   1.31022218E+02      ANOM PER    =   8.95454718E+01       O-DOT   =   -2.98500882E+00
 TAU =   1.47183512E+03      NODL PER    =   8.95733762E+01       U-DOT   =    1.80695353E+00

DATE,...    ME,MM,ST,DT       X,Y,Z,R          DX,DY,DZ,V         LAT,...       ALPHA,...      REV,...
 3/ 1/80       124.17951   1.52277091E+07   7.24373193E+03   35.64248315  332.26799211    1.39095    HMIN-MAX
  0/34        1474.17951  -8.00558073E+05  -1.62398049E+04  164.74734072   36.45836070    1.00000
10.77669      2053.77659   1.27108410E+07  -1.87825496E+04   80.53158     89.93718500     .00000
                  .16657   2.13901362E+07   2.58643741E+04   36.63826196  205.17776128     .00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z        4.8632969920E+11   -4.5859856415E+11    1.4824971848E+11    5.4297935713E+10
    VELOCITY MAG,X,Y,Z        1.1845296305E+05   -2.6806672461E+04   -1.0110749391E+05   -5.5585802510E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z        1.3411468424E+09    1.1792460131E+09   -5.9019309473E+08   -2.4438860547E+08
    VELOCITY MAG,X,Y,Z        2.4175913103E+04    8.8241346016E+03   -1.3578769765E+04   -1.7950666689E+04
RHO  =   5.08247223E-12
  A  =   2.17507126E+07      MEAN ANOM   =   9.56268833E+00       APOGEE  =    3.63991544E+03
  E  =   1.69134032E-02      ECCENTRIC   =   9.72548074E+00       HEIGHT  =    2.01844662E+02
  I  =   1.10003960E+02      TRUE ANOM   =   9.88964539E+00       PERIGEE =    3.51949837E+03
  O  =   1.36650514E+02      KEPL PER    =   8.95346263E+01       HEIGHT  =    8.14275942E+01
  U  =   1.30882103E+02      ANOM PER    =   8.95432260E+01       O-DOT   =   -2.97968187E+00
 TAU =   1.47180130E+03      NODL PER    =   8.95711424E+01       U-DOT   =    1.80526015E+00

DATE,...    ME,MM,ST,DT       X,Y,Z,R          DX,DY,DZ,V         LAT,...       ALPHA,...      REV,...
 3/ 1/80       133.65399   1.56434783E+07  -5.80836121E+03   -.00000000   316.66633106    1.50000    DSC NODE
  0/43        1483.65399  -1.47590335E+07  -5.52111027E+03  146.77060097    -.00000000    1.00000
39.23923      2519.23923  -5.53397537E-05  -2.41861658E+04   95.66054     89.29016325    0.00000
                  .16657   2.15069171E+07   2.57399840E+04   -.00000000   199.39772802    0.00000
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POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z      4.8632635353E+11   -4.5871750173E+11    1.4819471996E+11    5.4264393238E+10
    VELOCITY MAG,X,Y,Z      1.1635548061E+05   -3.9848250764E+04   -3.1492207845E+04   -5.0990796520E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z      1.3468917546E+09    1.1805590448E+09   -5.9543324104E+08   -2.5662623181E+08
    VELOCITY MAG,X,Y,Z      2.4061435471E+04   -4.2320002223E+03   -3.9580720118E+03   -2.3353257775E+04
RHO  =   1.62567026E-12
  A  =   2.17743228E+07      MEAN ANOM   =   4.45386547E+01     APOGEE   =   3.64610282E+03
  E  =   1.74434399E-02      ECCENTRIC   =   4.52484197E+01     HEIGHT   =   2.07473650E+02
  I  =   1.09937728E+02      TRUE ANOM   =   4.59626154E+01     PERIGEE  =   3.52108245E+03
  O  =   1.36666331E+02      KEPL PER    =   8.96805494E+01     HEIGHT   =   8.24532840E+01
  U  =   1.34037385E+02      ANOM PER    =   8.95410548E+01     O-DOT    =  -2.95631797E+00
 TAU =   1.47255983E+03      NODL PER    =   8.95693995E+01     U-DOT    =   1.80122848E+00

DATE,...    ME,MM,ST,DT        X,Y,Z,R          DX,DY,DZ,V        LAT,...        ALPHA,...      REV,...
 3/ 1/80       135.00000    1.51023537E+07  -7.56605055E+03    -5.23116530   314.76969416    1.51529
  0/45        1485.00000   -1.52248597E+07  -4.90705225E+03   144.53653358    -5.19633740    0.00000
 0.00000      2700.00000   -1.95028167E+06  -2.40743967E+04    100.15353      89.23498218    0.00000
                 .16667     2.15336751E+07   2.57073921E+04    -5.23017400   200.08407136    0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z      4.8632657533E+11   -4.5872079134E+11    1.4818739986E+11    5.4259380577E+10
    VELOCITY MAG,X,Y,Z      1.1517837104E+05   -4.1694437713E+04   -3.9778634008E+04   -5.3879237307E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z      1.3470005807E+09    1.1801458087E+09   -5.9568398132E+08   -2.5850924365E+08
    VELOCITY MAG,X,Y,Z      2.4105607222E+04   -5.9902554559E+03   -2.2437298700E+03   -2.3241403042E+04
RHO  =   1.25738019E-12
  A  =   2.17736721E+07      MEAN ANOM   =   4.96923028E+01     APOGEE   =   3.64552624E+03
  E  =   1.73123426E-02      ECCENTRIC   =   5.04572514E+01     HEIGHT   =   2.06849534E+02
  I  =   1.09937398E+02      TRUE ANOM   =   5.12264855E+01     PERIGEE  =   3.52144488E+03
  O  =   1.36666350E+02      KEPL PER    =   8.96766299E+01     HEIGHT   =   8.27681739E+01
  U  =   1.34394279E+02      ANOM PER    =   8.95403874E+01     O-DOT    =  -2.95723972E+00
 TAU =   1.47262156E+03      NODL PER    =   8.95683314E+01     U-DOT    =   1.80133491E+00

DATE,...    ME,MM,ST,DT        X,Y,Z,R          DX,DY,DZ,V        LAT,...        ALPHA,...      REV,...
 3/ 1/80       150.00000    1.76229996E+05  -1.31709930E+04   -59.35194986   279.03913269    1.58342
  1/ 0        1500.00000   -1.18771777E+07   1.30861678E+04   105.04571131   -59.18289594    0.00000
 0.00000      3600.00000   -1.88039426E+07  -9.95742703E+03    167.95572      89.12040983    0.00000
                 .16667     2.18943750E+07   2.52571013E+04   -59.34409456   221.93454417    0.00000
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POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z       4.8633944152E+11   -4.5876475910E+11    1.4811516369E+11    6.4203402408E+10
    VELOCITY MAG,X,Y,Z       1.0084787647E+05   -5.3132533997E+04   -7.1790898953E+04   -4.5764505209E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z       1.3368747227E+09    1.1682204761E+09   -5.8913782628E+08   -2.7461156222E+08
    VELOCITY MAG,X,Y,Z       2.5321635048E+04   -1.7601405077E+04    1.5752649203E+04   -3.1230358923E+03
RHO  =   7.70881366E-14
  A  =   2.17252469E+07      MEAN ANOM  =   1.16011628E+02      APOGEE  =   3.63705699E+03
  E  =   1.72118380E-02      ECCENTRIC  =   1.16691157E+02      HEIGHT  =   1.99435722E+02
  I  =   1.10020721E+02      TRUE ANOM  =   1.17767323E+02      PERIGEE =   3.51397460E+03
  O  =   1.36689269E+02      KEPL PER   =   8.93775317E+01      HEIGHT  =   7.63533246E+01
  U  =   1.28302359E+02      ANOM PER   =   8.95371794E+01      O-DOT   =  -2.99369070E+00
TAU  =   1.47119765E+03      NODL PER   =   8.95550684E+01      U-DOT   =   1.80983947E+00

DATE,....   ME,MM,ST,DT        X,Y,Z,R          DX,DY,DZ,V         LAT,...       ALPHA,...     REV,...
 3/ 1/80      165.00000   -1.34591164E+07   -1.16391807E+04   -50.65828782   162.94010451    1.84658
  1/15       1515.00000    4.13025467E+06    1.76365515E+04   345.18641591   -50.46947667    0.00000
 0.00000     4500.00000   -1.70601752E+07    1.33652123E+04     203.30279     89.84628993    0.00000
                 .16667    2.21151409E+07    2.50029474E+04   -50.64775784   327.46768176    0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z       4.8635990539E+11   -4.5881059237E+11    1.4805397642E+11    5.4178017762E+10
    VELOCITY MAG,X,Y,Z       8.4587334878E+04   -4.5644080635E+04   -5.7245815651E+04   -2.3444304260E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z       1.3165686938E+09    1.1544088805E+09   -5.7152908370E+08   -2.7211719664E+08
    VELOCITY MAG,X,Y,Z       2.5743430166E+04   -1.0076012971E+04    2.0306178415E+04    1.4209996517E+04
RHO  =   2.51941451E-14
  A  =   2.17350602E+07      MEAN ANOM  =   1.71215145E+02      APOGEE  =   3.64106649E+03
  E  =   1.78734415E-02      ECCENTRIC  =   1.71368831E+02      HEIGHT  =   2.02565994E+02
  I  =   1.10016341E+02      TRUE ANOM  =   1.71521183E+02      PERIGEE =   3.51319521E+03
  O  =   1.35744074E+02      KEPL PER   =   8.94381960E+01      HEIGHT  =   7.46947160E+01
  U  =   1.33306813E+02      ANOM PER   =   8.95384293E+01      O-DOT   =  -2.99847434E+00
TAU  =   1.47246341E+03      NODL PER   =   8.95663299E+01      U-DOT   =   1.80813844E+00

DATE,....   ME,MM,ST,DT        X,Y,Z,R          DX,DY,DZ,V         LAT,...       ALPHA,...     REV,...
 3/ 1/80      165.04675   -1.34916948E+07   -1.15901566E+04   -50.50522594   162.78711245    1.84709   HMIN-MAX
  1/15       1515.04675    4.17970291E+06    1.76214352E+04   345.02170462   -50.31621894    0.00000
 2.30494     4502.80494   -1.70225994E+07    1.34273909E+04     203.30314     93.34935203    0.00000
                 .16667    2.21193272E+07    2.50028305E+04   -50.49463477   327.58569490    0.00000

POSITION AND VELOCITY RELATIVE TO SUN
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    DISTANCE MAG,X,Y,Z       4.8635996001E+11   -4.5991072033E+11    1.4805378778E+11    6.4177952089E+10
    VELOCITY MAG,X,Y,Z       8.4555694614E+04   -4.5535004288E+04   -3.7260948866E+04   -2.3392132970E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z       1.3165110061E+09    1.1543806867E+09   -5.7147214714E+08   -2.7207727645E+08
    VELOCITY MAG,X,Y,Z       2.6752696758E+04   -1.0027008508E+04    2.0291071781E+04    1.4263179525E+04
RHO  =   2.51909180E-14
  A  =   2.17352237E+07      MEAN ANOM  =   1.71389069E+02     APOGEE  =   3.64106871E+03
  E  =   1.79664063E-02      ECCENTRIC  =   1.71539693E+02     HEIGHT  =   2.02565575E+02
  I  =   1.10016259E+02      TRUE ANOM  =   1.71688310E+02     PERIGEE =   3.51324680E+03
  O  =   1.36744138E+02      KEPL PER   =   8.94392050E+01     HEIGHT  =   7.47436672E+01
  U  =   1.33321691E+02      ANOM PER   =   8.95384307E+01     O-DOT   =  -2.98838247E+00
 TAJ =   1.47245571E+03      NODL PER   =   8.95663314E+01     U-DOT   =   1.80810996E+00

DATE,...    ME,MM,ST,DT        X,Y,Z,R            DX,DY,DZ,V          LAT,...        ALPHA,...      REV,...
 3/ 1/80        157.31472  -1.43008539E+07  -9.07935985E+03  -42.87306778   156.37454562    1.87155    BETA =90
  1/17         1517.31472   6.51791060E+06   1.66753923E+04  338.04059390   -42.68121779    0.00009
18.89291       4638.98291  -1.49981497E+07   1.62672723E+04    202.51041    89.99999999    0.00000
                   .16667   2.21238170E+07   2.50025525E+04  -42.86239431   332.25626509    0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z       4.8636245631E+11   -4.5881575553E+11    1.4804057531E+11    6.4174967549E+10
    VELOCITY MAG,X,Y,Z       8.3248623426E+04   -4.3081675813E+04   -3.8207806708E+04   -2.0542504850E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z       1.3138496326E+09    1.1531841720E+09   -5.6877061927E+08   -2.6993597718E+08
    VELOCITY MAG,X,Y,Z       2.6693831820E+04   -7.5171675342E+03    1.9345503257E+04    1.7103271207E+04
RHO  =   2.56650263E-14
  A  =   2.17434299E+07      MEAN ANOM  =   1.80000000E+02     APOGEE  =   3.64111199E+03
  E  =   1.74943941E-02      ECCENTRIC  =   1.80000000E+02     HEIGHT  =   2.02519995E+02
  I  =   1.10012141E+02      TRUE ANOM  =   1.80000000E+02     PERIGEE =   3.51590433E+03
  O  =   1.36743543E+02      KEPL PER   =   8.94598561E+01     HEIGHT  =   7.73123315E+01
  U  =   1.33823053E+02      ANOM PER   =   8.95382511E+01     O-DOT   =  -2.98376991E+00
 TAJ =   1.47256373E+03      NODL PER   =   8.95661614E+01     U-DOT   =   1.80683315E+00

DATE,...    ME,MM,ST,DT        X,Y,Z,R            DX,DY,DZ,V          LAT,...        ALPHA,...      REV,...
 3/ 1/80        173.15128  -1.50300679E+07   5.12585377E+03   -.00000000   136.75852259    2.00000    ASC NODE
  1/29         1523.15128   1.50750883E+07   6.04795515E+03  315.45732882    -.00000000   89.57022
 9.07653       5343.07653  -9.00100265E-04   2.36373709E+04    177.63344    90.72705931    0.00000
                   .16667   2.29050304E+07   2.51565654E+04   -.00000000   340.00223200     .18357

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z       4.8636908515E+11   -4.5884202938E+11    1.4799284746E+11    6.4163822901E+10
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   VELOCITY MAG,X,Y,Z       8.4643731654E+04   -2.7963248615E+04   -7.8839495391E+04   -1.3173849785E+04

POSITION AND VELOCITY RELATIVE TO MOON
   DISTANCE MAG,X,Y,Z       1.3062134059E+09    1.1531626731E+09   -5.5831621399E+08   -2.5434580206E+08
   VELOCITY MAG,X,Y,Z       2.7094293069E+04    7.6830554143E+03    8.7205368387E+03    2.4474365531E+04
RHO  =    5.51478763E-14
  A  =    2.17722136E+07     MEAN ANOM   =    2.30604340E+02     APOGEE   =    3.64270418E+03
  E  =    1.65935226E-02     ECCENTRIC   =    2.29877341E+02     HEIGHT   =    2.04640616E+02
  I  =    1.09337758E+02     TRUE ANOM   =    2.29159170E+02     PERIGEE  =    3.52378685E+03
  O  =    1.36759523E+02     KEPL PER    =    8.96676194E+01     HEIGHT   =    8.57232848E+01
  U  =    1.30845830E+02     ANOM PER    =    8.95373230E+01     O-DOT    =   -2.96775786E+00
TAU  =    1.47171310E+03     NODL PER    =    8.95652579E+01     U-DOT    =    1.80172547E+00

DATE,...    ME,MM,ST,DT       X,Y,Z,R            DX,DY,DZ,V          LAT,...        ALPHA,...      REV,...
 3/ 1/80       130.00000   -1.55907865E+07    7.19590004E+03     3.15743580   135.61590662    2.00327
  1/30        1530.00000    1.53570223E+07    5.02135443E+03   314.10195122     3.13634155    0.00000
 0.00000      5400.00000    1.20302831E+06    2.35971175E+04   174.92393      90.76677742    0.00000
                  .16657    2.1988313?E+07    2.51757628E+04     3.15641023   339.97084466    0.00000

POSITION AND VELOCITY RELATIVE TO SUN
   DISTANCE MAG,X,Y,Z       4.8636307381E+11   -4.5983342031E+11    1.4798880663E+11    5.4163151343E+10
   VELOCITY MAG,X,Y,Z       8.5270713921E+04   -2.6732254859E+04   -7.9866391579E+04   -1.3214735272E+04

POSITION AND VELOCITY RELATIVE TO MOON
   DISTANCE MAG,X,Y,Z       1.3061674218E+09    1.1535812512E+09   -5.5789818116E+08   -2.5310114299E+08
   VELOCITY MAG,X,Y,Z       2.7071102867E+04    8.7527436633E+03    7.5941229779E+03    2.4434230557E+04
RHO  =    5.01347810E-14
  A  =    2.17720092E+07     MEAN ANOM   =    2.34174723E+02     APOGEE   =    3.64293229E+03
  E  =    1.66667301E-02     ECCENTRIC   =    2.33409007E+02     HEIGHT   =    2.04895665E+02
  I  =    1.09937873E+02     TRUE ANOM   =    2.32645039E+02     PERIGEE  =    3.52349144E+03
  O  =    1.36758527E+02     KEPL PER    =    8.96663565E+01     HEIGHT   =    8.54548146E+01
  U  =    1.30632763E+02     ANOM PER    =    8.95363387E+01     O-DOT    =   -2.96788483E+00
TAU  =    1.47157335E+03     NODL PER    =    8.95649830E+01     U-DOT    =    1.80176784E+00

DATE,...    ME,MM,ST,DT       X,Y,Z,R            DX,DY,DZ,V          LAT,...        ALPHA,...      REV,...
 3/ 1/80       135.00000   -2.53775458E+06    1.93996341E+04    57.28513250   102.48678268    2.17594
  1/45        1545.00000    1.14595809E+07   -1.30123343E+04   277.21256047    57.10988372    0.00000
 0.00000      6300.00000    1.81498349E+07    1.04375815E+04   121.49345      90.92287167    0.00000
                  .16657    2.16143170E+07    2.55853426E+04    57.27916407   320.91922945    0.00000

POSITION AND VELOCITY RELATIVE TO SUN
   DISTANCE MAG,X,Y,Z       4.8635896142E+11   -4.5886084968E+11    1.4790850779E+11    5.4146956438E+10
   VELOCITY MAG,X,Y,Z       1.0243800209E+05   -1.4571774894E+04   -9.7905476333E+04   -2.6375605148E+04
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POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z        1.3163824677E+09    1.1691326232E+09    -5.5938867507E+08    -2.3540023819E+08
    VELOCITY MAG,X,Y,Z        2.5940359800E+04    2.0350146628E+04    -1.0336457615E+04     1.1275139350E+04
RHO  =    4.46119747E-13
  A  =    2.17261756E+07       MEAN ANOM   =    2.88650101E+02     APOGEE   =    3.63613029E+03
  E  =    1.69031427E-02       ECCENTRIC   =    2.87727281E+02     HEIGHT   =    1.97053836E+02
  I  =    1.10019149E+02       TRUE ANOM   =    2.86802034E+02     PERIGEE  =    3.51520730E+03
  O  =    1.35779771E+02       KEPL PER    =    8.93833585E+01     HEIGHT   =    7.61309476E+01
  U  =    1.36541534E+02       ANOM PER    =    8.95351104E+01     O-DOT    =   -2.99295513E+00
 TAU =    1.47333183E+03       NODL PER    =    8.95639042E+01     U-DOT    =    1.80991690E+00

DATE,...     ME,MM,ST,DT          X,Y,Z,R            DX,DY,DZ,V           LAT,...         ALPHA,...       REV,...
 3/ 1/80        210.00000    1.30840067E+07    1.18965345E+04    50.34617506    342.72073821     2.34770
  2/ 0         1561.00000   -4.07001958E+06   -1.81678993E+04   153.68624361     50.15697127     0.00000
 0.00000       7200.00000    1.64210624E+07   -1.40375656E+04        92.75371     90.09452536     0.00000
                   .16667    2.13870891E+07    2.58583799E+04    50.34173452    212.29171036     0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z        4.8634051417E+11   -4.5987579465E+11     1.4781657194E+11     6.4112103846E+10
    VELOCITY MAG,X,Y,Z        1.1702727375E+05   -2.2058027552E+04    -1.0306642533E+05    -5.0854097255E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z        1.3372404438E+09    1.1951470352E+09    -5.7250952789E+08    -2.3537366836E+08
    VELOCITY MAG,X,Y,Z        2.4387278037E+04    1.3440809142E+04    -1.5488918 96E+04    -1.3197627707E+04
RHO  =    4.12031279E-12
  A  =    2.17331333E+07       MEAN ANOM   =    3.54173752E+02     APOGEE   =    3.63407009E+03
  E  =    1.69076464E-02       ECCENTRIC   =    3.54085239E+02     HEIGHT   =    1.35941281E+02
  I  =    1.10015478E+02       TRUE ANOM   =    3.53983960E+02     PERIGEE  =    3.51955735E+03
  O  =    1.36836724E+02       KEPL PER    =    8.94263027E+01     HEIGHT   =    8.14285431E+01
  U  =    1.31208555E+02       ANOM PER    =    8.95349392E+01     O-DOT    =   -2.98890022E+00
 TAU =    1.47201348E+03       NODL PER    =    8.95627897E+01     U-DOT    =    1.80968234E+00

DATE,...     ME,MM,ST,DT          X,Y,Z,R            DX,DY,DZ,V           LAT,...         ALPHA,...       REV,...
 3/ 1/80        211.35300    1.39864303E+07    1.03182492E+04    45.51054327    339.45061043     2.36332   BETA =90
  2/ 1         1561.35300   -5.52333322E+06   -1.76084921E+04   149.37694559     45.31814043    44.03829
21.19002       7231.18002    1.52054634E+07   -1.58872523E+04        81.50578     90.00000000     0.00000
                   .16667    2.13853585E+07    2.58635823E+04    45.50609513    209.12356325     0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z        4.8633917280E+11   -4.5887764851E+11     1.4780822654E+11     6.4107899473E+10
    VELOCITY MAG,X,Y,Z        1.1765138247E+05   -2.3534902417E+04    -1.0250750293E+05    -5.2703384935E+04
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POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z      1.3388836685E+09    1.1411747343E+03   -3.7374434439E+08   -2.3752107441E+08
    VELOCITY MAG,X,Y,Z      2.4283385142E+04    1.1451851542E+04   -1.4329231591E+04   -1.5034713055E+04
RHO  =   4.6751166E-12        RHOSP   =   2.3457176E-12      PH+.554 =   1.60891717E+02
SMT  =   1.97023385E+01
  A  =   2.17387648E+07      MEAN ANOM  =   3.60000000E+02      APOGEE   =   3.63590373E+03
  E  =   1.62553609E-02      ECCENTRIC  =   3.60000000E+02      HEIGHT   =   1.97842805E+02
  I  =   1.10012796E+02      TRUE ANOM  =   3.60000000E+02      PERIGEE  =   3.51957735E+03
  O  =   1.35940330E+02      KEPL PER   =   8.94610530E+01      HEIGHT   =   8.15164292E+01
  U  =   1.30924598E+02      ANOM PER   =   8.95341234E+01      O-DOT    =  -2.38585538E+00
 TAU =   1.47183134E+03      NODL PER   =   8.95621313E+01      U-DOT    =   1.80772883E+00

DATE,...    ME,MM,ST,DT       X,Y,Z,R          DX,DY,DZ,V         LAT,...        ALPHA,...     REV,...
 3/ 1/80      213.71813    1.52418370E+07    7.33215373E+03    35.74487547   332.51184408    2.39064   HMIN-MAX
  2/ 3       1563.71813   -7.93033432E+05   -1.62334604E+04   142.54527721    36.56055846    0.00000
43.19801     7423.08971    1.27417845E+07   -1.87511505E+04    30.62305      89.83705974    0.00000
                 .16657    1.13905019E+07    2.58531852E+04    35.74364888   205.21205563    0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z      4.8533712734E+11   -4.5388121124E+11    1.4779377157E+11    5.4100211179E+10
    VELOCITY MAG,X,Y,Z      1.1842454559E+05   -2.6618357183E+04   -1.0113371383E+05   -5.5569250457E+04

POSITION AND VELOCITY RELATIVE TO MOON
    DISTANCE MAG,X,Y,Z      1.3414762319E+09    1.1876491855E+03   -3.7377115341E+08   -2.3986552336E+08
    VELOCITY MAG,X,Y,Z      2.4151077633E+04    8.8747561422E+03   -1.3554111896E+04   -1.7310871139E+04
RHO  =   5.03512304E-12
  A  =   2.17497337E+07      MEAN ANOM  =   9.63473991E+00      APOGEE   =   3.63919637E+03
  E  =   1.67117576E-02      ECCENTRIC  =   9.79695786E+00      HEIGHT   =   2.01158092E+02
  I  =   1.10007965E+02      TRUE ANOM  =   9.96123979E+00      PERIGEE  =   3.51956803E+03
  O  =   1.36945414E+02      KEPL PER   =   8.95225444E+01      HEIGHT   =   8.15297512E+01
  U  =   1.30637863E+02      ANOM PER   =   8.95317655E+01      O-DOT    =  -2.98046424E+00
 TAU =   1.56132240E+03      NODL PER   =   8.95595869E+01      U-DOT    =   1.80605331E+00

DATE,...    ME,MM,ST,DT       X,Y,Z,R          DX,DY,DZ,V         LAT,...        ALPHA,...     REV,...
 3/ 1/80      223.22051    1.56913503E+07   -5.78724855E+03    -.00000000   316.85152094    2.50000   DSC NODE
  2/13       1573.22051   -1.47086384E+07   -6.63787072E+03   124.50285720     -.00000000    0.00000
13.23032     7333.23032   -6.77773106E-04   -2.41849891E+04    95.71932      89.29364733    0.00000
                 .16657    2.15077743E+07    2.57383456E+04    -.00000000   199.99613539    0.00000

POSITION AND VELOCITY RELATIVE TO SUN
    DISTANCE MAG,X,Y,Z      4.8633375333E+11   -4.5890011531E+11    1.4773858735E+11    5.4066477987E+10
    VELOCITY MAG,X,Y,Z      1.1595917859E+05   -3.9727149887E+04   -3.1541138636E+04   -5.1003466741E+04
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APPENDIX C

"REAL WORLD" EPHEMERIS TAPE AND ITS FORMAT

The real world data tape was generated on Control Data Corporation (CDC) 6000 series machines. It is an unlabeled binary tape written in odd parity at a density of 556 bpi.

A seven-track non-return-to-zero (change-on-ones) recording scheme is used. Magnetic particles on the tape are aligned in either the positive or negative direction. A binary "1" is recorded by reversing the alignment (polarity); no polarity reversal results in a "0."

A frame of tape data consists of one 6-bit data character and one parity (check) bit for each character. Tracks 0 through 5 specify the characters while track 6 holds the parity bits (see Figure C-1). In binary

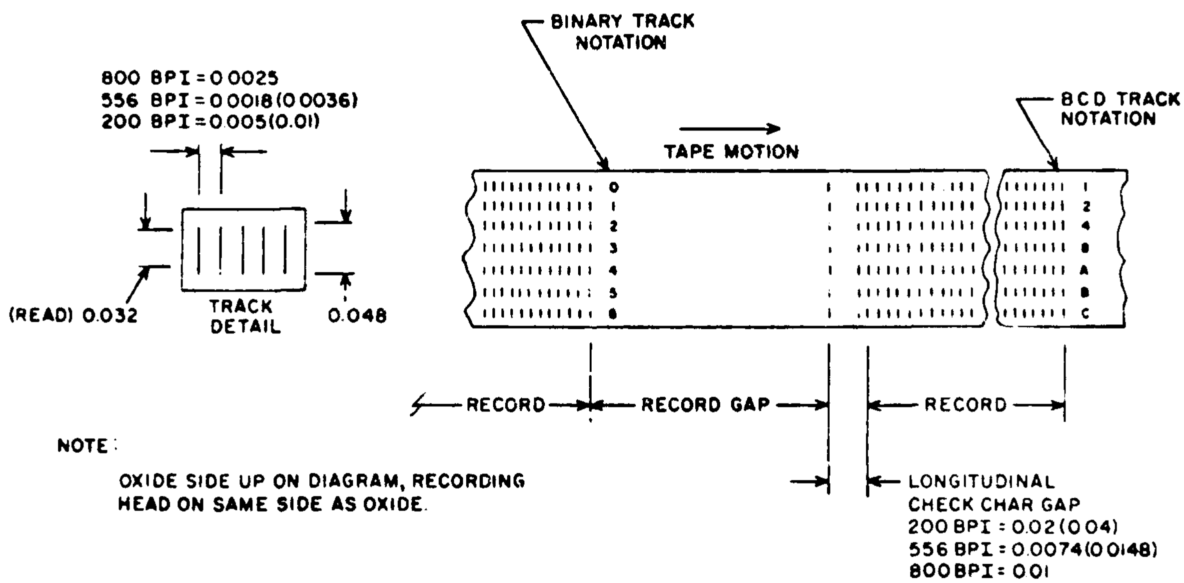

Figure C-1. Bit Assignments on Tape

format, the parity bit is chosen so that the total number of "1" bits in any line is odd. Additional information on the CDC tape processing hardware and procedures is available in CDC Publication No. 60156100.

CDC employs a 60-bit floating point word; its format is shown in Figure C-2. Floating point arithmetic takes advantage of the ability to

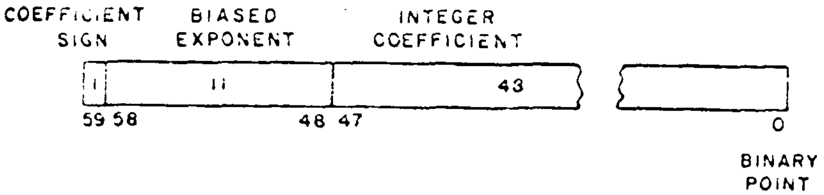

Figure C-2. Floating Point Format

express a number as kB^n, where k = coefficient, B = base number, and n = exponent. The base number is constant (2) for binary-coded quantities and is not included in the general format. The binary point is considered to be to the right of the coefficient, thereby providing a 48-bit integer coefficient, the equivalent of about 14 decimal digits. The sign of the coefficient is carried in the highest order bit of the packed word. Negative numbers are expressed in one's complement notation. The 11-bit exponent carries a bias of 2^{10}(2000_8) when packed in the floating point word. The CDC procedure used in floating point arithmetic is described in CDC Publication No. 60100000.

The tape contains one file which consists of 216 records. Each record contains 501 words; each word is 60 bits.

The first word in each record is a bookkeeping word; it is an integer quantity equal to the number of data words in that record. Since there are no short records on this tape, this word is always the integer 500. The remaining 500 words are segmented into 50 data frames of 10 words each. Table C-1 gives the ordering and units of the 10 data words.

All position, velocity, and acceleration components are given in an ECI coordinate frame. The X axis of this coordinate system is pointed toward the mean equinox of date at 0 hr GMT of the date of epoch. The X and Y axes form the plane of the true equator at epoch. The Z axis is perpendicular to the true equator at epoch. The set is right handed, with Y lying east of X and Z being positive north.

Table C-1. Data Frame Format

Word	Quantity	Description and Units
1	time	Time, sec from epoch
2	X	ECI vehicle position, ft
3	Y	
4	Z	
5	$\dot{X}$	ECI vehicle velocity, fps
6	$\dot{Y}$	
7	$\dot{Z}$	
8	$\ddot{X}_D$	ECI total atmospheric drag acceleration, ft/sec^2
9	$\ddot{Y}_D$	
10	$\ddot{Z}_D$	

The data rate on the tape is one data set for each 10 sec. The first time on the tape is 0 sec; it corresponds to the epoch time of 22 hr 30 min 0 sec GMT on 29 February 1980. The last time on the tape is 107990 sec.

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